

Information Systems for Supporting Fire Emergency Response

by

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ABSTRACT

Despite recent work on information systems, many first responders in emergency situations are unable to develop sufficient understanding of the situation to enable them to make good decisions. The record of the UK Fire and Rescue Service (FRS) has been particularly poor in terms of providing the information systems support to the fire fighters' decision-making during their work. There is very little work on identifying the specific information needs of different types of fire fighters. Consequently, this study has two main aims. The first is to identify the information requirements of several specific members of the FRS hierarchy that lead to better Situation Awareness. The second is to identify how such information should be presented.

This study was based on extensive data collected in the FRS brigades of three counties and focused on large buildings having a high-risk of fire and four key fire fighter job roles: Incident Commander, Sector Commander, Breathing Apparatus Entry Control Officer and Breathing Apparatus Wearers. The requirements elicitation process was guided by a Cognitive Task Analysis (CTA) tool: Goal Directed Information Analysis (GDIA), which was developed specifically for this study. Initially appropriate scenarios were developed. Based on the scenarios, 44 semi-structured interviews were carried out in three different elicitation phases with both novice and experienced fire fighters. Together with field observations of fire simulation and training exercises, fire and rescue related documentation; a comprehensive set of information needs of fire fighters was identified. These were validated through two different stages via 34 brainstorming sessions with the participation of a number of subject-matter experts.

To explore appropriate presentation methods of information, software mock-up was developed. This mock-up is made up of several human computer interfaces, which were evaluated via 19 "walkthrough" and "workshop" sessions, involving 22 potential end-users and 14 other related experts. As a result, many of the methods used in the mock-up were confirmed as useful and appropriate and several refinements proposed.

The outcomes of this study include: 1) A set of "GDI Diagrams" showing goal related information needs for each of the job roles with the link to their decision-making needs, 2) A series of practical recommendations suitable for designing of human computer interfaces of fire emergency response information system, 3) Human computer interface mock-ups for an information system to enhance Situation Awareness of fire fighters and 4) A conceptual architecture for the underlying information system. In addition, this study also developed an enhanced cognitive task analysis tool capable of exploring the needs of emergency first responders.

This thesis contributes to our understanding of how information systems could be designed to enhance the Situation Awareness of first responders in a fire emergency. These results will be of particular interest to practicing information systems designers and developers in the FRS in the UK and to the wider academic community.

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Chapter 1 : Introduction

1.1 Background to Research Problem

Emergencies bring long lasting suffering to any society, community or a country. Disasters or catastrophes such as the New York 9/11 incident, the London 7/7 bombing, the South Asia tsunami, the Sichuan earthquake in China and more recently the earthquake in Haiti provide strong evidence for such emergencies. Traditionally, most of the research related to emergencies is concentrated on the response of commercial firms to emergencies or crises, largely restricted to the corporate environment or focused on the public relations aspects of a crisis (Turoff et al., 2004; Jennex, 2007). Since the 9/11 incident, there is an increasing interest in proposing improvements in the ability to respond to emergencies with the aim of minimising the severity of the impact caused by an emergency (Turoff et al., 2004). However, the majority of these early efforts are focused on infrastructure improvements to mitigate the impacts of the disasters (Turoff et al., 2004). This has created a gap in the research directly related to response work during emergencies.

Emergency Response (ER) failures are mostly due to the fact that first responders at individual, team, and organizational levels are unable to make comprehensive decisions in an appropriate manner (Son and Pena-Mora, 2006). There are many examples like the firefighter deaths in 9/11 (Son et al., 2007), the mass casualties during Bhopal Incident (Endsley, 1999), the Three Mile Island nuclear reactor meltdown (Jennex, 2007) and the recent firefighter deaths in the UK (BBC News 24, 2007) that reinforce the argument. Therefore, it is widely accepted that on-site dynamic information retrieving, sharing and presenting, in the right format at the right time and to the right person, will significantly improve the decision-making of first responders (Carver and Turoff, 2007; Manoj and Baker, 2007; Turoff et al., 2004; Turoff 2002; Jennex, 2007).

It is a well-known fact that over the last few decades, the acquisition and successful introduction of Information Technology (IT) and Information Systems (IS) has improved both the public and private sector business decision-making. However, progress made into IS/IT related work to support ER work is slow and comparatively inadequate (Bergstrand and Landgren, 2009; Woodhall, 2007). Despite its slow progress, interest has increased during the last decade with proposals for ER systems models, architectures and frameworks

(Jennex, 2004, 2007; Turoff et al., 2004; Lee and Bui, 2000; Meissner et al., 2002; 2006). Also with the increased popularity of state of the art mobile technologies, wireless sensor networks and various other communication and information technologies, many efforts have been made to produce: actual systems, system prototypes and working models to support first responders (Bergstrand and Landgren, 2009). Some of the significant research work in ER information systems has been carried out in relation to: Medical and Triage (Lorincz et al., 2004; Rosen et al. 2002; McGrath et al, 2003; Massey et al., 2006), Hurricanes (Iakovou and Douligeris, 2001), Floods (Katuk et al., 2009; Lanfranchi and Ireson, 2009), Building Collapses (Betts et al., 2005), Earthquakes (Jang et al. 2009; Lien et al., 2009), Fire Emergencies (Jiang et al., 2004a, 2004b; Wilson et al., 2005; Bergstrand and Landgren, 2009; May et al., 2007; Klann, 2008; Walder et al., 2009; Gambardella et al., 2008; Yuan and Detlor, 2005), Forest fire (Wybo, 1998; Avesani et al., 2000; Alonso-Betanzos et al., 2003; Lee et al., 2002; Coen et al., 2007) and generic emergency response (Kanchanasut et al., 2007; Ramrekha and Politis, 2009; Adams et al., 2008; Potter et al. 2007; Otim, 2006; Madey et al., 2006). However, so far, even the systems consisting of the most advanced information technologies do not seem to meet the expectations of the emergency responders (Van de Walle and Turoff, 2007). Therefore, the need to study and understand the design and development of ER information systems that support first responder decision-making remains a major research agenda within the information systems discipline.

As explained by Turoff et al. (2004), the majority of the ER systems related work is concentrated on the underlying technology of the underlying networks and physical facilities. Most of the systems address the issue of the lack of information during ER to support decision-making. To generate new information, these systems propose new technologies or technology related concepts. Thus, such efforts are classified as technology driven systems (Endsley et al., 2003b). Many of the systems design and development efforts that are aimed to support ER work overlook the understanding of the human aspects of the end-users who operate in difficult environments (Carver and Turoff, 2007). Often these works disregard relevant aspects of human computer interaction (Denef et al., 2009). Therefore, the failures and limitations of information systems that support complex time-critical operations are often caused by the bias towards technology during the systems design (Bolstad et al., 2006).

On the other hand, there are some noteworthy efforts made in ER domains to understand the physical and mental behavioural implications, working patterns, contextual implications of emergency responders (Landgren, 2007; Klann, 2007; Deneff et al., 2008; Dyrks et al., 2008; 2009; May et al., 2007). All these efforts acknowledge the significance of understanding human aspects in the systems design process and provide useful in-depth understanding into various ER operations. However, indirectly most of these investigations are restricted to some selected technologies, thus presentation of their findings is limited to the scope of these selected technologies. Although these studies are more user-centric, most of the system development efforts have failed to recognize the decision-making implications unique to the time-critical complex domains. Very little acknowledgement is made on the differences in needs created by different responder job roles and their level of experience. Most of the human centered explorations are strictly focused on understanding a particular need, issue, task or a job. Consequently, there remains a pressing and timely need for further research to study a user centred approach to information systems design that supports emergency first responders during their decision-making. Thus, this study attempts to explore the requirements of different first responder job roles with the aim of designing an information system to support decision-making during ER operations.

Another important strand in IS systems for supporting time-critical complex domains similar to ER is the impact of end-user's Situation Awareness (SA). Essentially, ER information systems should support first responders by enhancing their SA leading to better decision-making (Klann et al., 2008). Key studies that recommend IS models and architectures suitable for ER have identified that the ability of IS to provide support to understand and recognise the situation or context of the responders is a key criteria of a better ER information system (Jennex, 2007; Turoff et al., 2004). Although not exclusively focussed on SA, several ER system development efforts also acknowledge the importance of enhancing first responder SA (Betts et al., 2005; Lanfranchi and Ireson, 2009; Madey et al., 2006; Bergstrand and Landgren, 2009). Several studies in ER related decision-making have described SA as one of the crucial inputs for better decision-making (Klein, 2000; Wohl, 1981; Bryant, 2002). In addition, most of the work on the theories and concepts of SA also recognises its close relationship with the decision-making, especially related to time-critical and complex domains (Endsley et al., 2007; Adams et al., 1995; Smith and Hancock, 1995). Several studies that explore SA revealed the importance of SA for decision-making in time-critical complex domains and how SA capable systems could

better support such decision-making (Endsley and Rodgers, 1994; Endsley and Robertson, 2000; Riley et al., 2006; Resnick, 2003; Albers, 1999; Connors et al., 2008). These works clearly suggest that although the individual elements of SA can vary widely from one domain to the next, the importance of SA as a foundation for decision-making and performance applies to almost every time-critical and complex domains (Endsley and Connors, 2008). Therefore, maintaining a high-level of SA is essential for effective decision-making. Further, this SA related work indicates that designing information systems to assist individuals to develop and maintain SA facilitates their decision-making activities leading to better performance (Endsley and Connors, 2008).

The above discussion explains that during emergency response there exists a clear link between the input of meaningful information, SA, first responder decision making and their performance. As shown in Figure 1.1 they can be positioned in a clearly defined sequence.



Figure 1.1: Link between Information, SA, Decision Making and Performance

Related to various ER domains there are a number of recent and past catastrophic incidents that clearly indicates poor ER performance due to failures occurred in the link between information received by first responders, SA and decision making. For example it was reveal that human decision-making failures at the Bhopal Union Carbide plant was due to misread of wrongly presented information that led to SA failure causing human decision making error (Endsley, 1999), firefighter deaths during 9/11 (Son et al., 2007) and in Three Mile Island nuclear meltdown it was identified that inappropriately designed human interface failed to deliver accurate information has led to SA lapses and finally decision making error in reactor shut down sequence (Itoh and Inagaki, 1997). In more recent emergency in the UK four firefighters were dead mainly due to inappropriate commitment decision to send firefighters into a blazing warehouse without any casualty to be rescued (BBC News 24, 2007). It was later revealed that main cause for such performance failure was due a decision making error of one of the officers who was unable to form required level of SA caused by inadequate information of the context. These examples clearly

indicate how failure in the above explained relationship could lead to poor performance and ultimately become a catastrophe. According to Endsley et al. (2003b) 88% of human error during complex time critical situations that led to poor performance was found to be due to issues with SA. In majority of these cases, operators do not make bad decisions or execute their actions poorly; they misunderstood the situation they are in. As experienced in the above explained examples in ER environments decision making is highly dependent on the SA. Fuelled by the appropriate information, SA is the engine that drives the train for decision making and performance during ER situations. Thus the best way to support emergency responder's performance during ER is to better support the development of high levels of SA created by the right information presented in right format at the right time.

There have been SA based IS design and development efforts in time-critical complex domains such as aviation (Endsley and Rodgers, 1994; Endsley and Robertson, 2000) and military (Riley et al., 2006; Connors et al., 2008). These systems development efforts aim to enhance end-user's SA to improve their decision-making. These efforts are primarily guided by the SA oriented design approach. The SA oriented systems design approach essentially focuses on understanding SA requirements consisting of dynamic information needs and information presentation or delivery needs of individual end-users (Endsley et al., 2003b). While there are many efforts in other time-critical complex domains, there is very minimal IS design and development efforts such as the Blandford and Wong (2004) and Son et al. (2007) that focus on understanding SA requirements of emergency responders as a means of supporting decision-making leading to their performance. ER domains lack research based on SA despite its strong influence to the decision-making and systems design in many other time-critical domains. Consequently, there is a timely need for more SA based research related to various ER operations. Thus, this study's attempt to explore the requirements of emergency first responders will be focused on enhancing and maintaining their SA to make better decision-making.

1.2 Context of the Study

Among many other types of emergencies, fire emergency is identified as one of the frequent and most life threatening emergencies that can cause losses to life, property and environment of a society or a country (Directgov, 2008). Fire emergencies cause enormous losses to economies of the countries (USFA, 2009a; ODPM, 2003). Also, over time fire

emergencies have cost many lives of emergency first responders (USFA, 2009b; Grimwood, 2008; Bretschneider et al., 2006). Although the cause of most of the fire emergency deaths of both casualties and responders are due to severe burns, structural collapses and explosions, smoke inhalation and falling from heights (McKinsey & Company, 2002; BBC News 24, 2007), often the root cause for such fatalities is inadequate SA, which led to decision-making failures (Son et al., 2007).

Historically, compared to other complex time-critical domains such as military or aviation, the worldwide sector of fire ER is slow in adopting technology to substitute or replace their traditional systems, method and procedures (Landgren, 2007; Bergstrand and Landgren, 2009). So far most of the research in the fire emergency domain, which aims to provide systems support for firefighting, is focused on the command and coordination of ER work that takes place in relatively safe and less restrictive environments (Denef et al., 2009). Moreover, majority of the past initiatives are focused on how Fire and Rescue Services can improve the existing systems, methods and procedures rather than to seek to replace them with something new. In addition, most of the research supporting actual firefighters during their response operations (Jiang et al., 2004a; 2004b; Wilson et al., 2005; Bergstrand and Landgren, 2009; Walder et al., 2009; Gambardella et al., 2008; Yuan and Detlor, 2005) is technology centered, and thus unable to understand the needs of the firefighters comprehensively. Most of this research has little focus on understanding the information needs of fire fighters and their requirements related to presentation or delivery of information. Rather they are focused on a few specific needs related to firefighters or some generic needs common to fire emergencies. More recently, there are some fire ER related studies (Denef et al., 2008; Dyrks et al., 2009; May et al., 2007) that are more user-centric. However, they often failed to recognize the different needs of different responder job roles.

The Fire and Rescue Service (FRS) of the United Kingdom (UK) has put high-levels of investment in technology and systems with the expectations of significant improvement in their response work. The importance of new information technology and systems within the UK FRS is highlighted after the catastrophic incidents such as 9/11 in the US and 7/7 bombing in the UK. Despite some progress made in acquiring supporting technologies and systems, so far UK FRS has failed to reach the expected support from their investments (NAO, 2009). To make the conditions worse, the progress of most of the government projects on supporting fire ER is slow, and completion has been delayed by several years

(NAO, 2009). Although there are several organisational and economic reasons for the slow progress and delays, inadequate knowledge and understanding of the actual needs of the firefighters are identified as one of the main causes (NAO, 2010). In the UK, most of the past academic research in fire ER related information systems is not focused on the response phase of a fire emergency but primarily focused on supporting the other functional phases such as prevention, preparedness, and mitigation (Yang and Frederick, 2004). The limited ongoing academic research projects do not provide due attention in supporting the individual decision-making needs of different firefighter job roles during the response phase of a fire emergency. Almost all the commercial and academic research efforts in systems development are confined to the use of several predefined technologies and concentrate on the limited and isolated needs that can be supported by some of the selected core technologies. Thus, currently UK's fire and rescue first responders lack support to understand the context of an emergency. Many of the UK's firefighters still have limited access to the contextual information on the building, occupants and/or the location of the hazard. Firefighters do not know whether they should enter the building, whether it is safe to enter and therefore, how to deal with a hazard most efficiently (Yang and Frederick, 2004). The recent deaths of four firefighters in Warwickshire due to lapses in the decision-making process could be cited as a classic example (BBC News 24, 2007).

Whilst the interest in providing IS/IT support for UK FRS has increased over the last few years (CLG, 2009a), the support expected for fire ER operations in large built environments having a high-risk of fire has also increased significantly among many other types of operations of the FRS (ODPM, 2003). However, very little academic research has so far addressed the needs of the firefighters related to the design and development of an information system supporting fire ER operation in these situations.

Therefore, there is still a pressing need for well-focused research to provide insights into how to design and develop an information system supporting firefighters of the UK FRS in general and with regard to the fire ER in large-scale buildings with high-fire risks in particular. Consequently, this study is primarily focused on exploring design and development of IS to support UK FRS operations in large industrial and commercial structures, which may contain a variety of dangerous hazards ranking in the category of high-fire risk.

The UK FRS provides an excellent research environment for information systems research for several reasons. First, the UK FRS is a large and complex organization and is likely to exhibit many of the issues that are found in other ER related sectors and fire emergencies in particular. Second, historically, the UK FRS has lagged behind in its investment and use of IS/IT in comparison to other complex time-critical organizational sectors. However, after the catastrophic events in the early years of the new millennium ambitious goals were set for the uptake of technology and systems over very short timescales. Consequently, there is increasing pressure on practitioners involved in the design and development of these systems to speed up the progress of the ongoing projects and in particular to match the expectations of the potential system users. Since most of these projects are new, both locally and internationally, there are only limited opportunities for all the stakeholders involved in these projects to learn from their mistakes and to benchmark other similar systems. Therefore, UK FRS is keen to contribute to research projects, which explore design and development of systems, supporting firefighters during their response operations. Third, obtaining access to FRS or any other ER related organizations and their resources is always a challenge compared to most other business environments. It is very important to have a strong link between the FRS and the researcher to carry out successful in-depth explorations within the context of FRS. For this particular study, the selection of UK FRS is appropriate as it contributes to the “SAFETYNET” (SAFETYNET, 2009); a research project funded by the UK government with the aim of developing an IS based on wireless technologies to support fire ER. Importantly, UK FRS acts as the end-user collaborator of the “SAFETYNET” project. Thus, the ability of the researcher to gain access to the UK FRS operations, resources and its staff is thought to be easier than in other ER sectors, because of the recent inclination of the FRS towards IS/IT research and its close link to the “SAFETYNET” project.

1.3 Research Questions and Objectives

The analysis of the current limitations in providing information systems support for the decision-making of fire emergency first responders leads to the main theme of this study, which is centered around two fundamental questions.

Research Question 1

What are the information requirements that will lead to better SA of different frontline fire responder job roles during response operations?

Research Question 2

How should an information system present or deliver the required information to enhance SA of different frontline fire responder job roles?

It was envisaged that it would be possible to address these issues by exploring the ER work of UK FRS. More specifically, the primary objectives of this study are:

1. Explore the information requirements of several specific job roles of the UK fire and rescue during a fire emergency.
2. Explore the presentation and sharing of such information to firefighters belonging to the specific job roles.
3. By recognizing suitable technology and its appropriate synergies, explore the information systems architecture required to present and share such information during a fire emergency.

1.4 Research Scope of the Study

At the outset of the study, it is important to clearly identify and understand the scope. The scope of this study is defined as follows:

- Fieldwork and analysis will be limited to 2 Years.
- Getting enough access to FRS to carry out an in-depth study is naturally difficult. Therefore, explorations will be limited to a few FRS brigades, which are expected to provide a satisfactory level of accessibility to its resources and its fire sites throughout the research. Interviews and explorations will be carried out in FRS brigades in the East Midlands UK.
- Field observations will be confined to simulated fire ER training activities and firefighter training observation.
- This research will be focused on large-scale physical structures having a high-risk of fire.
- Due to the limitations of the resources, investigations will be carried out only among several important job roles during a fire emergency.

1.5 Roadmap of the Thesis

The following paragraphs describe the organization of the remaining chapters of this thesis.

Chapter 2: Literature Review

Aim of the Chapter: To explore and identify significant gap in the literature related to information system supporting fire emergency response.

Structure of the Chapter:

- Reviews the literature concerned with emergency management and response especially focused on the fire emergency.
- Discusses decision-making related to ER and firefighter decision-making.
- Reviews the systems support available for ER decision-making.
- Discusses SA as another important strand in systems supporting ER.
- Reviews systems design and development based on the SA requirements.
- Explores the key developments related to the fire ER in UK and recent experience related to the use of information systems and technology to support the response activities of UK FRS.

Outcome of the Chapter: Significant gap in the literature related to compressive needs of different types of firefighters that is essential to enhance their SA with the support of information systems is identified.

Chapter 3: Research Design & Methodology

Aim of the Chapter: To provide the overall design and the methodological overview to achieve the objectives of the Study

Structure of the Chapter:

- Describes the work carried out in deciding an appropriate philosophical view for answering the research questions and further discusses a suitable research methodology.
- Explains the development and application of an innovative technique for gathering information requirements from firefighters.
- Discusses the techniques to be used to explore the deployment and presentation of information needs of the firefighters.
- Describes the steps and method undertaken in the development of a conceptual information system architecture to support the final objective of this study.

Outcome of the Chapter:

- 1) Clear definition of the research philosophy of the study.
- 2) Development of cognitive task analysis tool; GDIA to elicit information requirements of firefighters,

- 3) Techniques to be used to explore the deployment and presentation of information needs of the firefighters.
- 4) Steps and method to propose conceptual information system architecture supporting fire ER.

Chapter 4: Elicitation of Information Requirements and Analysis

Aim of the Chapter: To identify comprehensive information requirements of four core fire fighter job roles and explain the complete process of requirement elicitation.

Structure of the Chapter:

- Introduces the operational context of the UK FRS.
- Explains the selection of important job roles to conduct the study.
- Provides background information on the three FRS brigades selected to carry out the exploratory work of this study.
- Explain the selection process of the appropriate primary and secondary high-risk incident sites and the development of fire incident scenarios.
- Explains the details of the information requirements elicitation efforts carried out with the use of the tool: Goal Directed Information Analysis (GDIA). This includes the stages of 1) Task Elicitation 2) Goal Elicitation and Validation 3) Elicitation of Decision and Information Requirements 4) Development and Validation of Goal-Decision-Information (GDI) Diagrams for the firefighter job roles being investigated.

Outcome of the Chapter:

1. Primary and secondary cases selected, Fire Scenarios and Four job roles selected for the study.
2. Validated goal hierarchies of four firefighter job roles.
3. Validated information requirements of four core fire fighters in the form of Goal-Decision-Information Diagrams.

Chapter 5: Development of the Information System Mock-up

Aim of the Chapter: To specify and develop software mock-up of an information system, for enhancing the SA of firefighters during fire ER.

Structure of the Chapter:

- Explains design considerations related to the selection of appropriate design guidelines and principles to be used in the development process of the human computer interface mock-ups.
- Explains important contextual factors exclusive to fire Emergency Response (ER) that may influence the mock-up design.
- Explains specific design decisions adopted in the process of developing the interfaces proposed
- Describes in detail some of the features and functionality of the proposed interfaces by considering several example interfaces.

Outcome of the Chapter:

1. Specific Design Decisions to guide the design and development of information system supporting firefighters,
2. Software mock-up consisting of human computer interfaces capable of support four fire fighter job roles during fire ER.

Chapter 6: Evaluation of the Information System Prototype

Aim of the Chapter: To explore the appropriateness and usefulness of the developed software mock-ups by analysing the outcomes of a series of end-user demonstration sessions.

Structure of the Chapter:

- Explains the organization of the end-user demonstration sessions.
- Explains the process of eliciting relevant and useful participant's feedback.
- Discusses the analysis of end-user feedback into various themes for evaluating or improving the performance of the proposed system.
- Discusses important themes considered under several headings in detail.

Outcome of the Chapter:

1. Significance and relevance of the factors that may cause SA failures and their general impact on designing information system supporting firefighters.
2. Overall appropriateness and usefulness of the interfaces to presentation of information for supporting fire fighters during ER,
3. Strengths and Limitations of specific interfaces proposed

4. Recommendations to overcome the interface limitations and suggestions to further improve already embedded functionality,
5. Several important general points about the development process of a fire ER system, information requirements and content of the interfaces.

Chapter 7: Information Systems Architecture for Fire and Rescue ER

Aim of the Chapter: To propose conceptual Information Systems Architecture (ISA) for a system supporting fire ER to large-scale built environments.

Structure of the Chapter:

- Discusses on the design approach
- Defines and introduces the layers of the architecture.
- Explains in-depth on the components and the functionality of the each layer of the architecture.
- Explains some challenges and opportunities for existing technologies to implement the architecture proposed and recognizes some future research needs.

Outcome of the Chapter: Conceptual layered architecture representing an “Owner’s” View of an information system supporting fire ER.

Chapter 8: Discussion and Conclusions

Aim of the Chapter: To Discuss the findings and results of this study in the context of the existing literature and make direct reference to the results from various stages of the research project.

Structure of the Chapter:

- Explains the research gap explored in this study.
- Summarises what the study has accomplished and Contributions.
- Discusses implications arising from the study findings and its impact.
- Explains the limitations of the study in detail.
- Discusses recommendations for further research.

Outcome of the Chapter:

1. A summary of the study’s findings and their contribution to existing knowledge.
2. Evidence of the impact of this research for academia and practitioners.
3. Limitations of the study and recommendations to overcome them.
4. Avenues of future inquiry and research.

Chapter 2 : Literature Review

2.1 Introduction

In the past two decades, emergencies have gained increased attention by IS/IT researchers, especially after the events such as the 9/11 attack, the London 7/7 bombing, the Tsunami in South Asia, the Hurricane Katrina in USA and the Earthquake in China (Landgren, 2007, Van de Walle and Turoff, 2007). The majority of the ER operation failures result from the fact that first responders are unable to develop an in-depth understanding of their situation (Son et al, 2007). The Fire and Rescue Service (FRS) is one of the main emergency related organizations, which suffer decision-making failures due to the limitations of information (McKinsey & Company, 2002; Yang and Frederick, 2004, BBC News 24, 2007). With some major changes in the organizational policies (ODPM, 2003) and considerable investment in the technology, the UK FRS expects significant improvements in the systems support for decision-making during fire ER. Consequently, this chapter reviews the literature concerned with: Emergency management and response, especially focused on the fire emergency, decision-making related to ER and firefighter decision-making, systems support available for ER decision-making, Situation Awareness (SA) and systems design and development based on the SA requirements. This chapter also explores the key developments related to the fire ER in UK.

2.2 Emergency and Emergency Management

Rosenthal et al. (2001) suggests that an emergency is a serious threat to the basic structures or the fundamental values and norms of a social system, which under time pressure and highly uncertain circumstances necessitates making critical decisions. Boin (2004) argues that this definition applies to all types of disruption. In contrast, a much simpler definition by Cronan (1998) defines emergency as a sudden and unexpected event threatening the safety of people, property or the environment and which therefore, requires immediate action.

The Federal Emergency Management Agency (FEMA), one of the major disaster coordinating agencies, defines emergency management as the preparation for and the carrying out of all emergency functions necessary to mitigate, prepare for, respond to, and recover from emergencies and disasters (FEMA's Emergency Management Higher

Education Project, 2007). de Leoni et al. (2007) suggest a simpler definition as they define emergency management as the coordinated activities both to prevent disaster happenings and to face them when they take place. Management of an emergency can be conceptualized as consisting of four interrelated functional areas; prevention, preparedness, response and mitigation, which are related to the disaster-life cycle (Drabek and McEntire, 2003). A slightly different, but more popular and widely cited definition, defines these functional phases as mitigation, preparedness, response, and recovery (FEMA's Emergency Management Higher Education Project, 2007). There are also many other definitions, but almost all of them introduce four functional phases to manage an emergency.

2.2.1 Response Phase of an Emergency

The Response phase is one of the four core functional areas of emergency management (Landgren, 2007; Drabek and McEntire, 2003). During this phase, emergency responders are the key personnel responsible for timely preparedness and the ability to intervene rapidly in an emergency situation (Landgren, 2007; ODPM, 2003). Thus, time and temporality are critical aspects of such activities (Zerubavel, 1981). ER operations consist of many specific work rhythms (Reddy and Dourish, 2002) and temporary structures (Orlikowski and Yates, 2002). Introduction of new technology is likely to affect these work rhythms and temporal structures (Shen et al., 2006).

Drawing from the work of Orasanu and Connolly (1993) and Flin (1996), Landgren (2007) introduces five specific characteristics that make work during the response phase of an emergency unique: First, the time-critical aspects are related to the reactive nature of such activity. For example, there is time-pressure on the responders to physically intervene in a sudden event as quickly as possible (Burke and Hendry, 1997). Second, the time-critical aspects are also related to uncertainties and ambiguities caused by incomplete information (Klein, 2000). Third, the immediate actions are dependent on team-based collective actions and are to a large extent irrevocable and irreversible (Endsley et al., 2003b). Fourth, the situation is dynamic, leading to change and sometimes competing goals (Endsley et al., 2003a; 2003b; Albers, 1998). Finally, the actors involved are working on different time-scales (Brehmer, 1991) depending on their role and responsibility (Fredholm, 1997). Santos et al. (2008) explain that the response phase has a high degree of dynamism and uncertainty, demanding speed in the actions realized. The first responders are also often

confronted with stressful situations in unfamiliar and hazardous work environments (Son et al., 2007) making response more complex than other phases (Santos et al., 2008).

The time-critical nature and adverse conditions during the response phase often lead to an inadequate ER (Mckinsey & Company, 2002; NCSEA, 2003). First responders at individual, team, and organizational levels are unable to make decisions in an appropriate manner (Son and Pena-Mora, 2006). Decision-making is often difficult due to uncertainty and conflict situation (Shafir et al., 1993) and is fundamentally different from the style of rational decision-making common in other domains (Klein, 1989; Sinha, 2005a; Endsley et al., 2007). Consequently, it is important to explore the decision-making process of emergency responders.

2.2.2 Fire Emergency and Fire Emergency Response

In most communities the Fire and Rescue Service (FRS) is considered the primary organization for ER (Cronan, 1998) since fire emergencies predominate. In the United States, more people are killed by fires than all other natural disasters combined (USFA, 2009b). In the year 2008, because of fire, 3,320 civilians and 118 firefighters lost their lives in the United States (USFA, 2009b). Similarly, in Germany, approximately 550 civilians and 18 firefighter deaths were recorded in the year 2002 and on average there are nearly 210,000 yearly fire incidents (Bretschneider et al., 2006). Every year there are more than 40,000 accidental house fires in England, resulting in average of 285 deaths and 9,000 burn injuries (Yang and Frederick, 2004). In the UK, fire emergencies are one of the most frequent and life threatening emergencies compared to other man-made and natural disasters and emergencies (Directgov, 2008). Thus, fighting fires is an important way to save lives and reduce injuries and loss of property (Deng et al, 2001). FRSs have responsibility to promptly respond to fire related incidents as and when they occur and to avoid such incidents (Landgren, 2007, Fire Service Manual Volume 2: Incident Command, 2008). The primary aim of the FRS is to protect civilians and firefighters, as well as to minimize property and environmental damage (Fire Service Manual Volume 2: Incident Command, 2008; ODPM, 2003). The performance of FRS could be improved with appropriate use of technology by prompting changes to the prevailing response procedures and practices of the fire and rescue personnel (Landgren, 2007) and so the fire emergency response work of FRS is considered the underlying context of this study.

2.2.3 Fire Emergency Response – The UK Scenario

There are 63 separate FRS brigades in England, Wales, Scotland and Northern Ireland (Fire Service, 2009). FRSs in England and Wales employ about 33,000 wholetime (full-time) firefighters and around 12,000 retained (part-time) firefighters (Directgov, 2009).

Although the rate of deaths and injuries caused by fire emergencies in the UK are declining, the expected degree of improvement is not satisfactory (Bain et al., 2002). The UK government believes that there is significant scope for further improvements in fire ER. One priority is to improve the efficiency of FRS in responding to fire (ODPM, 2006). As in many other countries, the tragic events of September 11th 2001 in USA and the London 7/7 bombing have created a new dimension to the UK emergency preparedness and resilience (Mott MacDonald, 2003).

Changes have been made following the recommendations proposed in the survey conducted by Bain et al. (2002). Over the past few years, significant changes have been made in policies and procedures of UK FRS operations (ODPM, 2003; Mott MacDonald, 2003). Central Government has promised to invest £1bn through its Fire and Resilience Programme to increase resilience, enhance capability and improve efficiency in the FRS (CLG, 2009a).

Although the role of the FRS in the UK has expanded in recent years to terrorist related incidents, floods and roadside accidents, its main focus remains that of fighting and preventing fires related to buildings (ODPM, 2003). Among many different types of fires, building fires are most significant as they cause the highest financial and social impact (CLG, 2009b). The response operations in high-risk built environments such as large shopping malls, major hotels, hospitals, museums, high-rise office and housing complexes are identified as most serious. Government policy has been developed in response in terms of greater resilience to these types of incidents and improved capacity to handle such consequences (ODPM, 2003). Consequently, fire ER activities related to large-scale buildings in the UK are now an important area of research.

2.3 Decision-making during Emergency Response

Most management research is concerned with individuals making strategic decisions when they have several hours or days to think through the options, and carefully evaluate each in turn against their business objectives using decision analysis methods (Fire Service Manual Volume 2: Incident Command, 1999). This is typically the method of decision-making in which managers are trained, but in the case of a dynamic or time-critical situation, decisions must come almost automatically (Fire Service Manual Volume 2: Incident Command, 1999; 2008). In such situations, people do not consciously generate and evaluate options, but simply know the right thing to do (Flin, 1996). This may be called intuition, but when it comes to such judgements, highly sophisticated mental activity is taking place in the mind of an individual (Fire Service Manual Volume 2: Incident Command, 1999). Hence decision-making can be broadly divided into two categories (Kobus et al., 2001) :

- Analytical decision-making process
- Intuitive or naturalistic decision-making process

One of the most important areas of research related to complex decision-making comes from the studies conducted on the impact of stress in the decision-making process (Sinha, 2005a). This is important since most emergencies create high-levels of stress in the decision makers mind (Orasanu, 1997). The stress in subject-matter experts may come from their operational environment that they perceive to generate demands beyond their ability to cope (Wickens, 1992). According to Sinha (2005a), such stressors can be due to the external factors related to the situation or internal factors related to the individual. Several common stressors being identified as:

- Time pressure
- Changes in environmental conditions
- Lack of information
- Excessive information (information overload)

These factors influence the quality of the received information, information processing and the performance of decision makers (Wickens, 1992). Although in a less stressful situations decision makers tend to evaluate different alternatives, in an emergency situation they select the best course of action based on their job role, experience and the situation at hand. In such a situation, responders tend to take the option of naturalistic decision-making rather than analytical decision-making (Klein, 1997; Orasanu and Connolly, 1993).

2.3.1 Naturalistic Decision-making (NDM)

Research on NDM developed around the work of Klein et al. (1986), Klein (1989) and Klein (1993). The Classical decision-making paradigm is primarily built around analytical and heuristic approaches to decision-making (Hutton and Klein, 1999). Klein argues that being largely normative instead of descriptive, that research fails to capture critical aspects of how experts actually make decisions in time-critical complex domains (Endsley et al., 2007).

There are some models, which combine both classical and naturalistic paradigms to explain decision-making related to the complex time-critical domains. Most of these methods highlight the limitations of NDM research and propose combined decision-making models. For example, Bryant (2002) proposed a synthesis of NDM and heuristic approaches to overcome the limitations of pure NDM models. However, pure NDM models remain most cited and popular in most of the cognitively demanding, time-critical complex domains of ER (Sinha, 2005a; Endsley et al, 2007). Consequently, the decision-making implications addressed in this research are primarily based on the NDM approach.

There has been growing interest by applied psychologists in NDM (Klein, 1997). These researchers typically studied decision-making in a variety of domains such as air traffic control (Rodgers et al, 2000), nuclear power plants (Roth, 1997), commercial and military pilots (Amalberti and Deblon, 1992), fire emergencies (Klein, 1999; Klein and Klinger, 1991), flight decks, intensive care units/industries hospital trauma centers (Fire Service Manual Volume 2: Incident Command, 1999). Although some of these domains are contextually different to an emergency, in many ways they have similarities, including complexity, uncertainty, significant consequences, competing goals and time constraints (Zsombok and Klein, 1997). NDM research has important significance in understanding how commanders and their teams make decisions at the scene of an incident as it offers descriptions of what responders actually do in taking operational decisions in emergencies (Fire Service Manual Volume 2: Incident Command, 1999).

Dynamic Decision-making (DDM) is a form of NDM used in controlling an environment that changes rapidly and has an effect on the decision made by the operator him/herself (Klein, 1997; Zsombok, 1997). In DDM a series of decisions need to be made in the correct

order, but also at the correct point of time. Such requirements make the process of DDM very stressful and cognitively demanding (Klein, 1993; Danielsson, 2002).

Klein and his associates (Klein et al., 1986; Klein and Klinger, 1991; Klein, 1989; 1993) have conducted research in difficult operational environments including study of decision-making of urban fire ground commanders (Klein, 1999). They found that the fire ground decision-making did not fit in to any conventional decision-tree framework. Firefighters concentrate on assessing and classifying the situation in front of them. Once they recognized that they were dealing with a particular type of event, the firefighters usually knew the typical response needed to tackle it. They would then promptly evaluate the feasibility of such a course of action, imagining how they would implement it, to check whether anything important might go wrong. If they envisaged any problems, then the plan might be modified or another strategy would be considered if they decided to reject the plan. Therefore, it was evident that firefighters aim at a satisfactory rather than an optimal decision.

Based on these studies, Klein introduced a model: Recognition Primed Decision-making (RPD) (Klein et al., 1986) to explain the decision-making process during fire fighting operations (Klein, 1993; 1997). According to Klein and Klinger (1991) the RPD model can be summarised as follows:

- Situational recognition allows the decision maker to classify the task as familiar or prototypical.
- The recognition as familiar carries with it the recognition of the following types of information: plausible goals (*Example: saving the property is not feasible, but saving the adjacent house is*), cues to monitor (*Example: wind strength and direction*), expectancies about the unfolding of the situation *Example: should be able to bring the reddish flame under control within 5 min*), and typical actions (*Example: three separate streams and two converging streams of water will be necessary to save the adjacent house*).
- Options are generated serially, with the more typical course of action considered first.
- Option evaluation is also performed serially to test the adequacy of the option, and to identify weaknesses and find ways to overcome them.
- The RPD model includes aspects of problem solving and judgment along with decision-making.

- Experienced decision makers are able to respond quickly, by identifying a plausible course of action at the outset rather than having to generate and evaluate a large set of options.
- Under time pressure, the decision maker is poised to act while evaluating a promising course of action, rather than be paralyzed while waiting to complete an evaluation of different options. The focus is on acting rather than analyzing.

As shown in Figure 2.1, the RPD model has three application phases, where each variant suits a situation having a particular level of cognitive complexity (Klein and Klinger, 1991; Klein, 1993). The simplest application phase of RPD could be useful when the situation is recognized and the obvious reaction is implemented. A somewhat more complex phase may be applicable when the decision maker consciously evaluates the reaction, typically using imagination to uncover problems prior to carrying it out. In the most complex case, the evaluation reveals flaws requiring modification, or the option is judged inadequate and rejected in favour of the next most typical reaction.

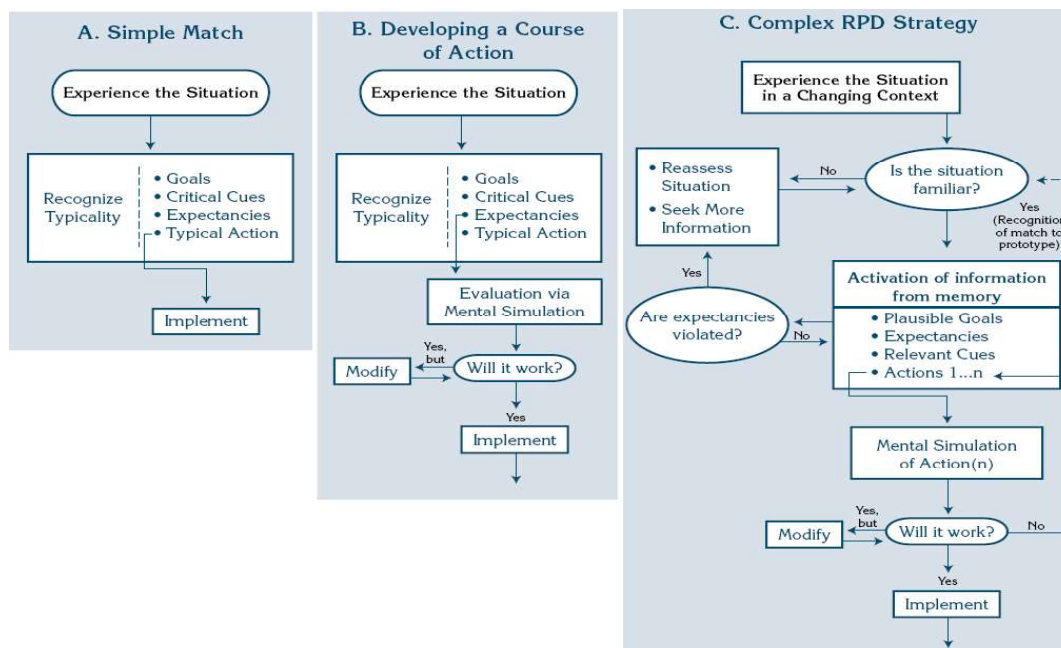


Figure 2.1: Versions of the RPD Model

2.3.2 Decision-making during Emergency Response and Responder's Experience

The RPD model asserts that complexity of the decision-making during an emergency is closely related to the experience of the decision makers (Klein, 1997). For example, an incident commander with previous experience of similar incidents will manage to find the

solution via the simplest application phase of the RPD model, yet less experienced commanders have to go through the complex second or third phase of the model (Klein, 1997). An experienced firefighter will be able to rapidly process the requisite information to make an appropriate decision (Klein et al., 1986). Veteran firefighters are able to evaluate a glut of information without any difficulty (Bouwsema, 2007). However, novice firefighters are not able to process the same amount of information in the time necessary to make a critical decision (Bouwsema, 2007). Since novice and expert firefighters have to work together it is important to enhance decision-making capabilities of both. In the FRS, the usual practice to improve the decision-making capabilities is to provide extensive training facilities and simulation practice to the firefighters so that their situation knowledge will improve. As a result, the state of experience of the novice firefighters is expected to improve (Bouwsema, 2007). Training and simulation practice is the conventional means of enhancing the decision-making ability of other types of emergency responders (Campbell et al., 2008; Connolly and Burgess, 2007). Currently this appears to be the prime means of reducing the gap of decision-making skills between experienced and novice responders. However, Klein (1997) stresses the importance of understanding the differences of the decision maker's experience when studying the decision-making requirements. Similarly, Militello and Hutton (1998) explain the importance of obtaining the views of the experts having different level of experience when studying their cognitive demands.

2.3.3 Decision-making during Emergency Response and Responder Job Roles

During ER operations, the responsibilities are usually shared among several different staff job roles, which vary depending on the complexity of the incident (Fire Service Manual Volume 2: Incident Command, 1999). Turoff et al. (2004) argue that in a crisis, it is never certain who will take on which role or which combination of roles. To maintain an appropriate hierarchy for a particular emergency, a responder often has to take the responsibilities of different job roles, regardless of their officially assigned designation or rank (Fire Service Manual Volume 2: Incident Command, 1999). During an emergency, there exists a possibility for the first qualified person active to immediately take on the highest priority role or roles they were pre-qualified for (Turoff et al., 2004). Decision-making tasks of responders vary from job role to job role depending on the responsibilities of the assigned job role (Fire Service Manual Volume 2: Incident Command, 1999).

Consequently, it is crucial to recognise the different needs of different job roles when study the decision-making during ER.

2.3.4 Decision-making during Emergency Response and Situation Awareness

According to the RPD model, experts use their expertise to evaluate situations and take typical courses of action (Klein, 1997). According to Klein (2000), such expertise usually builds on the level of Situation Awareness (SA) of a person. Situation Awareness will be discussed in detail in Section 2.5.

According to Klein (2000), SA is central to all three versions of the RPD model. For the first variation, the recognition of the situation is sufficient to lead to a course of action. The second variation requires effort to determine how to interpret the situation to understand how to proceed. In the third variation, the SA generates a course of action that is evaluated

Having considered many NDM related studies, Endsley et al. (2007) argue that NDM picks up where SA leaves off and concerns how decisions are made based on SA. Endsley and Robertson (2000) also argue that people's classification of the situation largely drives their decision-making and performance. Adams et al. (1995) explain the close relationship between SA and decision-making of the operators in their work related to SA and complex systems. Blandford and Wong (2004) suggest that complex decisions are not made in isolation but in the context of a dynamically changing situation, and awareness of this situation is therefore crucial. Son et al. (2007) also state that provision of a higher-level of SA is vital and essential for successful decision-making in an emergency. Lanfranchi and Ireson (2009) recognized SA as the key to effective decision-making during ER. Carver and Turoff (2007) confirm the above argument that emergency responders need to be adequately aware of the real situation to have confidence in making meaningful life-and-death decisions.

Blandford and Wong (2004) argue that SA during emergencies is important as the knowledge of the situation leads to a better "mental picture." In the case of dynamic changes in the situation, decision makers have to keep up with the SA to build up this picture, which can then be used to evaluate and predict the outcome of their plans. Endsley (1999) argues that most of the decision-making errors attributed to human operators are due to the errors in their SA. For instance firefighter decision-making failures due to inadequate

SA occurred in the 9/11 incident (Son et al., 2007). During this incident, firefighters did not have adequate awareness of the conditions in the World Trade Centre (WTC) buildings and what was happening elsewhere at the site (Sunder, 2004). The firefighters inside WTC1 were not aware when WTC2 collapsed and so did not evacuate (Mckinsey & Company, 2002). This led to more than 300 firefighter deaths (Berry et al., 2005). Moreover, the white boards that were set up at the incident site, on which records are kept of the identification of the fire crews on-site, their assignment, location and activities, were damaged and lost with the collapse of WTC 2 (Mckinsey & Company, 2002). Since there was no backup capability available, all information related to command, control, and accountability was lost (Sunder, 2004). This led to poor decision-making in the efforts of rescuing firefighters (Mckinsey & Company, 2002).

There is clearly a significant relationship between SA and the decision-making during the operations in time-critical complex domains, including the domain of ER, and so improved knowledge on the situation is vital for better decision-making, in these domains.

2.4 Information System Support for Decision-making during Emergency Response

It has been widely recognized in the emergency communities 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 the decision-making of first responders (Carver and Turoff, 2007; Manoj and Baker 2007; Turoff et al., 2004; Turoff, 2002; Jennex, 2007). The faster they analyze, and act on key information, the more effective their response will be (Van de Walle and Turoff 2007). Bellardo et al. (1984) identified the stress of decision-making during ER and explained the importance of having an ER System to assist first responder's decision-making. Jennex (2007) explains that one of the main purposes of ER system is to provide decision-making support during the emergency.

However, Van de Walle and Turoff (2007) argue that so far even the systems consisting of the most advanced information technologies did not seem to notably contribute to the ER work. According to Carver and Turoff (2007), one short sighted aspect related to the support of information systems in ER is the lack of understanding of the human aspects during the design and development. They argue that information systems that support ER

and the responders should work as a team to provide adequate decision-making support during an emergency. According to them, the best way to achieve this is by understanding the human implications related to the ER work. Van de Walle and Turoff (2007) conclude that the human role in ER information systems should not be neglected. de Leoni et al. (2007) argue that if designers devise systems without continually taking into account user impressions and needs, those systems are going to fail since they will not be used by real actors.

According to Endsley et al., (2003b) there are two major schools of thought in the literature of Human Factors (HFs) related to design of systems: the Technology Centered approach (Endsley et al., 2003b) and the User Centered approach (Endsley et al., 2003b; Maguire, 2001a). Endsley et al. (2003b) argue that traditionally systems have been designed from a technology centered perspective. Engineers developed the sensors and systems. They then provided a display for each system. As technology improved, more displays were added. People were left with the job of trying to keep up with the exponential growth of data created by this process. In the face of changing tasks and situations, the operator is called upon to find, sort, integrate, and process the information needed from all that is available, leading inevitably to an information gap (Endsley et al., 2003b). As an alternative to the downward spiral of complexity and error induced by this design philosophy, the user-centered design philosophy is a better mode of achieving more effective systems (Endsley et al., 2003b). User Centered Design (UCD) integrates user input into the design process of systems (Beirne et al., 1998). The Usability Professionals Association defines UCD as an approach to design that grounds the process in information about the people who will use the product (Usability Professionals' Association, 2009). UCD processes focus on users through the planning, design and development of a system (Usability Professionals' Association, 2009). UCD shifts the emphasis on design from mastery to usability by moving away from "*telling people what they should use*" to "*understanding what they need.*" Users express their needs and desires to researchers, who then translate them into practical solutions for designers and engineers to carry out the implementation. Furthermore, there is also a need to incorporate user feedback throughout the evaluation phases of the design process. Karat (1997) further explains that although the traditional systems design approaches have always declared the first step of any design process as "*To know the users and their tasks,*" these approaches have been much more tuned to well specified, narrow contexts than to the realities of the workplace. UCD challenges designers to

mould the interface on the capabilities and needs of the operators, rather than displaying information centered on the sensors and technologies producing such information. UCD integrates this information in a manner to suit the goals, tasks and needs of the end-users (Endsley et al., 2003b; Maguire, 2001a). In comparison to the technology centered design principles, this philosophy was born with the desire to obtain optimal functioning of the overall human-machine interaction (Endsley et al., 2003b). So far a variety of methods has been developed to support UCD of systems (Maguire, 2001a; Abras et al., 2004).

2.4.1 Emergency Response Information Systems

This section reviews some of the significant previous work related to the design and development of systems that support various ER operations. This review includes literature on ER information systems and systems models, frameworks and architectures. It pays special attention to the systems support for fire ER.

ER Systems Models, Frameworks and Architectures

Countries including USA, Canada, UK, and many other European countries have established models for their national ER information systems (Anelli, 2006). Bellardo et al. (1984) argue that no matter what the scale of an ER system it should consist of the basic components; a database, data analysis capability, normative models and interfaces. However, Jennex (2004) argues that this model is somewhat limited as it fails to address issues such as how the ER System fits into the overall ER plan, ER System infrastructure, multiple organization spanning, knowledge from past emergencies, and integrating multiple systems. Later, Jennex (2004) expanded the ER system model of Bellardo et al. (1984) to facilitate clear communications, improve the efficiency and effectiveness of decision-making and manage data to prevent information overload. Jennex (2007) argues that emergency responders, who are under stress, need systems that do more than just provide data. Emergency responders demand systems that can quickly find and display knowledge relevant to the situation in a format that facilitates the decision maker in making decisions (Jennex, 2007).

Turoff et al. (2004) recognised the need to improve the design and functionality of ER information systems. They develop a set of general and supporting design principles and specifications for a “Dynamic ER Management Information System” (DERMIS). This study introduces a framework for the development of flexible and dynamic ER information

systems. This framework addresses the communication and information needs of first responders as well as the decision-making needs of command and control personnel. Turoff et al. (2004) conclude that a system supporting emergency responders operate at various levels of command and control has to be a communication system tailored for the emergency response mission. This study also stresses the systems support for SA and proposes to use multiple templates for variety of actions that can be modified as needed. Turoff et al. (2004) urge that these templates should be able to be used by individuals, initiating notifications using Personal Data Assistants (PDAs). This work is based on a careful synthesis of earlier literature findings and significant historic emergency experiences rather than based on an actual elicitation of stakeholder needs.

Lee and Bui (2000) also proposed a template based ER system model where each template provides a standard set of placeholders or slots for representing the details of the activity. Rather than based on the dynamic online information this model is only capable of providing decision-making support based on historic data.

Meissner et al. (2002) proposed a comprehensive communication architecture to support a generic emergency situation. This work is based on the findings of an in-depth stakeholder needs related to the use of technology. They asked experts in the field what technology they currently use and what they missed (Meissner et al., 2002). Meissner et al. (2002) focused on the specific communication needs of responders working as frontline responders, on-site commanders and officers working at the command center. The approach suggested by Midkiff and Bostian (2001) appears to be similar to the work of Meissner et al. (2002). However, it does not address the needs of the responders deployed at the last “yard” of an incident. In their study Meissner et al. (2002), describe how frontline responders operating in difficult terrain may benefit from appropriate information systems. Later, Meissner et al. extended their work by introducing a conceptual information systems architecture MIKoBOS (Meissner et al, 2006). This was an attempt of developing a conceptual systems architecture suitable for supporting three different types of personnel involved in different levels of the organizational hierarchy. Meissner et al. (2002; 2006) highlight the importance of understanding in-depth needs of individual responders when proposing technological solutions to support ER. However, the architecture is only capable of addressing some of the common needs that could arise during any type of emergency.

“WORKPAD” is a communication architecture to support decision-making during ER operations (de Leoni et al., 2007). This architecture is based on a human centered approach. Requirements of the users were identified via a task analysis technique called Hierarchical Task Analysis combined with various emergency scenarios. However, “WORKPAD” does not support the individual needs of the frontline rescuers or firefighters as it is limited to the common needs of frontline team leaders and the officers located at the command centers.

Hwang et al. (2007) introduced a conceptual information systems architecture suitable for Community Service emergencies with the use of ad-hoc and mobile technologies. Kwan and Lee (2005) proposed an architecture for ER information system that uses GIS information collected from intelligent transportation systems and intelligent building management systems. Neither of these studies has identified the end-user requirements, rather they are technology driven.

Systems Support for ER

The work of Lorincz et al. (2004) related to medical care response proposed a common protocol and software framework: “CodeBlue,” which could integrate devices such as wearable vital sign sensors, handheld computers, and location tracking tags into disaster response scenarios. Although it is still at the early stage of development, its initial experience with sensor networks raised many exciting opportunities, which can be generalized into other ER scenarios including fire emergencies. Although predominantly technology driven, this study shows the benefits of a sensor network to support ER.

“ALADDIN” is a five year project started in 2006 (ALADDIN Project, 2006), which aims to model, design, and build decentralized systems that can bring together information from a variety of heterogeneous sources to take informed action (Adams et al., 2008). ALADDIN is considering different aspects such as data fusion, decision-making, machine learning, and system architecture (Adams et al., 2008).

“DUMBONET” describes an emergency network platform based on a hybrid combination of Mobile Ad-Hoc Network (MANET) and a satellite IP network operating with conventional terrestrial Internet. It is designed to support collaborative simultaneous ER operations deployed in several disaster-affected areas (Kanchanasut et al., 2007). “CHAMELEON” (Ramrekha and Politis, 2009) is another MANET based system solution

for extreme emergency situations such as forest fire and terrorist attacks. Similarly, Luglio et al. (2007) introduce an integrated system composed of a satellite segment and a MANET to support emergency scenarios. Furthermore, Jang et al. (2009) and Lien et al. (2009) looked at the possibility of deploying a “Rescue Information System for Earthquake Disasters” (RISED). These projects focused on promoting MANET based technologies to support emergency first responder decision-making during various natural disasters. However, they do not focus on end-user requirements.

Other ER related research includes, Otim (2006), Rosen et al. (2002), Potter et al. (2007), Tufekci (1995), “IMASH” (Iakovou and Douligeris, 2001) and “ARTEMIS” (McGrath et al, 2003). All these focus on improving emergency related decision-making. However, they only concentrate on introducing and promoting a variety of new communication and information technologies, mathematical models and methods, agent based systems and prototypes to generate and coordinate information suitable for supporting ER related operations. There is very little evidence on the human centered aspects related to these developments; instead they are taking technology centered approach.

Katuk et al. (2009) proposed a Web-based support system prototype for flood response operation in Malaysia. This work recognized the importance of acquiring the needs of the various responders during the systems design. With the use of a cognitive knowledge acquisition method, interviews and related document reviews were carried out to understand the requirements of experts belonging to several flood related ER organizations. Therefore, this study has taken a more user centric approach.

Massey et al. (2006) proposed “AID-N”; an information system that supports the frontline responders during mass casualty emergencies. The design of this system is based on a user centered approach, where user needs are identified prior to the system development (Gao et al., 2007). End-user needs were identified by having interviews with various types of officers related to mass scale triage situation, real-time observation of incidents and scenario based questioners. Furthermore, based on the initial requirements, a prototype of the system was developed. This was later evaluated in several iterations to obtain extended feedback that lead to a better system capable of accurately updating the frontline medical officers with real-time casualty information. This is one of the few ER system developments, which has taken a user centered design approach and recognized the

importance of identifying comprehensive needs of end-users. However, this work does not provide evidence whether it managed to identify the individual needs of responders representing different agencies and different jobs.

Aziz et al. (2009) proposed a working prototype of a system and its architecture to improve mobile computing support for professionals involved in a disaster response and recovery operation to facilitate better assessment of the damage caused to buildings. This system is capable of sharing the assessment information available to personnel within the disaster response area. Aziz et al. (2009) adopted the use of “Scenario-based User Needs Analysis” (SUNA) a scenario based technique to obtain user requirements for the prototype development. This prototype was developed in the context of fire and rescue operations. However, it focussed only on the specific needs of the firefighters related to assessment of building damages.

Betts et al. (2005) describe a prototype designed to improve first responder SA at emergency scenes, specifically in collapsed buildings. However, the authors do not clearly define what they meant by SA and how it effects the decision-making of the responders. They describe the importance of recognising the requirements of the responders and they managed to understand these requirements via several workshop sessions with the responders. However, there is not enough evidence to say whether this study has managed to understand the issues related to the SA.

“WeKnowIt” is a project aiming to enable both emergency responders and community citizens to participate during a flooding incident (Lanfranchi and Ireson, 2009). The authors identified the importance of having a user centered approach to enhance the end-users SA. They also recognized the importance of identifying the functional and non functional user needs prior to the design. This work is one of the few studies that recognize the importance of enhancing SA for better decision-making during ER. However, the authors do not clearly define what they meant by SA and the captured needs are very generic.

Madey et al. (2006) proposed “WIPER,” a prototype ER system capable of generating traffic forecasts and emergency alerts for engineering, public safety and ER personnel. They explored the possibility of improving SA issues for generic emergency situation with the use of mobile phones. As a means of supporting the decision-making of the responders,

this work has recognised the importance of enhancing the SA. However, the authors do not define what they meant by SA. Furthermore, there is no evidence on how they have captured situation related issues of the end-users.

Systems Support for Fire ER

Jiang et al. (2004a; 2004b) conducted various studies, including one on Large Displays for incident commanders and another was an information system prototype called “Siren.” Information outputs provided by both these studies were suitable for the decision-making of different stakeholders involved in a fire emergency. Based on an extensive field study of firefighting practices, “Siren” has been developed to support the communication between firefighters with multiple levels of redundancy in both communication and user alerts. This system was capable of gathering, integrating, and distributing contextual data, such as location and temperature. As a proof of concept, a system prototype has been evaluated with the firefighters and it was found to be useful to improve many aspects of their current work practices.

The creators of “Siren” were never explicit on their method of knowledge elicitation. Their research was guided by using pervasive computing technologies for fire emergency context. Despite such shortcomings, the key findings of the study have shown: first, that the firefighters often have formed an incomplete picture of the situation. Second, the dynamic nature of fires often quickly reduces the reality and validity of collected information. Finally, experienced firefighters had to compensate for lack of information by making quick visual assessments of the nature of a fire. Such findings reinforce the difficulties in decision-making and importance of having more understanding of the context of fire fighting.

Jiang et al. (2004b) have also designed basic prototypes suitable for incident commanders (ICs). In their field study, they had identified key design implications to be considered during the development process of prototypes for firefighters: *Accountability* of resources and personnel, *Assessment* of the situation, *Resource allocation* and, *Communication* support. They proposed a paper based prototype to look after information requirements of ICs. However, their work did not seek to capture in-depth requirements for each of these key implications and the extent to which their prototypes meet these implications is not discussed.

Some of the work of Jiang et al. (2004b) appeared to be complementary to the work of Camp et al. (2000). Camp et al. (2000) specifically looked at the communication issues in emergencies and made a prototype of a radio system that would reduce congestion while maintaining contextual awareness of both commanders and officers at the command centers. However, in contrast, Jiang et al. (2004b) concentrated more on supporting ICs via large visual displays.

The work of Jiang et al. (2004a; 2004b) was extended by the study “FIRE” (Wilson et al., 2005). The objective of this study was to enhance the operation procedures of firefighters by utilizing new technologies. The “FIRE” system consists of two modules: one for an Incident Commander (IC) and the other for an individual fire-fighter. The IC module includes a graphical user interface indicating the location of firefighters in buildings and health status of firefighters. Individual fire-fighter module consists of a mobile computer and heads-up micro-display mounted inside the oxygen mask (Lloyd, 2005). As well as face to face interviews, the source of information for this study was based on several large roundtable discussions, where groups of three to five firefighters would sit together and discussed the effectiveness of current technology and what investments should be made in new types of equipment. Interviews have indicated an ambivalent attitude to technology by firefighters. Though firefighters have welcomed the ideas like real-time tracking and health monitoring, they were concerned that technology, especially IT may be unreliable. Furthermore, they strongly believed that prolonged use of technology may create unhealthy dependence (Steingart et al., 2005). However, the findings of the “FIRE” project led to the development of a Head Mounted Display (HMD) prototype for frontline firefighters (Wilson et al., 2005; Wilson and Wright, 2007)

The “FIRE” project’s aim was only to provide wearable computing solution for the firefighters. By restricting investigations to a particular technological concept, this study has clearly limited knowledge of the dynamic information requirements of firefighters who work under changing cognitive demands. In fact, the “FIRE” project seems to be driven by the recommendations made in the McKinsey (McKinsey & Company, 2002), one of the independent reports on the 9/11 incident. However, there is no sign of a clearly defined theoretical framework being used by the authors to guide their exploration and analysis on the context of firefighters.

Bretschneider et al. (2006) also discussed the benefits of HMDs for the firefighters and evaluated the different design options. This study contradicts the findings of the “FIRE” project by highlighting the limitations of the monocular HMD proposed in the “FIRE” project.

Bergstrand and Landgren (2009) looked at the possibility of using a new class of information technology and associated information systems called mobile live video broadcasting. This project focused on how the mobile live video capabilities could improve SA between ER actors on accident sites and command centre settings. This work is one of the few studies that recognize the importance of firefighter SA, but is primarily focused on promoting a particular technology.

There have been several other studies such as, “CADMS” (Walder et al., 2009) and the work of Gambardella et al. (2008) specifically related to real-time location tracking of firefighters in and around the buildings. These studies are confined to a technological solution capable of solving a single isolated need of firefighters. Similarly, a project WearIT@WORK (WEARIT@WORK, 2010) conducted by some researchers at Fraunhofer FIT, Germany (Fraunhofer FIT, 2010) proposed a system prototype “LifeNet” capable of supporting firefighter navigation and location tracking (Klann, 2008). This system is also based on the mobile sensor and communication technologies and other wearable devices such as head mounted displays. However, this work acknowledges the importance of understanding human aspects related to the need of firefighter navigation (Klann, 2007). In this study, researchers used a board game and a virtual environment to simulate firefighter operations (Klann, 2007). They explored the contextual and behavioural issues of firefighters in designing a technological solution for firefighter navigation. Deneff et al. (2008) conducted a similar study to understand the human implications, their work behaviours and patterns, in designing navigational support for firefighters. The authors used an ethnographic approach and conducted two qualitative studies with the Paris FRS. During this study, authors observed firefighters in a usual work situation to get an insight of navigation practices and to look for opportunities for supportive technology. From the analysis of the videos, images, field notes and transcripts of the fieldwork, a set of core issues related to designing of a navigational aid are identified. Subsequently, Ramirez et al. (2009) presented two design concepts aimed at supporting firefighters in creating and finding their own paths. The same authors carried out a role-playing workshop related to a

firefighting scenario (Dyrks et al., 2009). This was done with the aim of developing a navigation “ubicom” infrastructure, leveraging the cognitive skills of firefighters. Fostering participatory design approach (Ehn, 1992) this workshop allowed software developers to understand firefighting equipment and tactical procedures. Also during the workshop, the system designers acquired ideas on Human Computer Interaction (HCI) concepts to manipulate navigational information on deployed landmarks. According to the authors, the workshop allowed them to identify how the new technology could be integrated to the firefighter navigation. However, none of these works made an effort to consider the positioning of this particular need among other needs of firefighters nor how to share the location tracking and navigation information among different firefighter job roles nor how can this particular information could be embedded with other information so that firefighter decision-making could be enhanced.

The work of May et al. (2007) describes the importance of understanding the requirements of the stakeholders involved in the fire emergency management in a tunnel. They specifically explain the importance of user centered design approach to design a system This was part of the “RUNES” project (RUNES, 2006) which focused on the creation of software tools that will enable the construction of systems that create or utilize existing large heterogeneous networks of computing devices (May et al., 2007). In the study, the end-user requirements were identified by having extensive interviews with the different responders and after visiting and observing tunnel related operations. Based on the end-user requirements, May et al. (2007) identified the challenges and opportunities for the use of wireless sensor networks to support tunnel fire emergency operations. Rather than recommending a technology to generate new information, the authors note *“The most effective technologies may be those where there are benefits to multiple stakeholders and where technologies can be incorporated into working practices without imposing additional demands on stakeholders.”* Thus, the work of May et al. (2007) is one of the few studies that acknowledge the importance of comprehensive understanding of responders requirements.

Landgren (2007) considers the distinctive characteristics that need to be carefully addressed when designing information technology to support fire ER work. This study specifically focused on how firefighters could make “sense” using IT. It also recognized the slowness of adopting innovative technologies into the fire and rescue operations and discusses the lack

of trust of firefighters towards using innovative information technologies. This work is based on nearly 700 hours of ethnographic studies with Swedish firefighters. Dyrks et al. (2008) also focused on the firefighter's sensemaking in their work related to WearIT@Work project. Their goal was to observe the sense making processes empirically, and find opportunities for providing ubiquitous computer based support for the firefighters. They took an empathic approach and participated in firefighter training. The authors considered this exercise with firefighters as an important part of their ethnographic work related to the WearIT@work project. The authors also identified that firefighters should play an active role to verify, complete or discard the existing information about the incident site. Thus, they conclude that the goal of a system for frontline firefighter navigation is far from giving directions but to support the firefighters on building their own paths. They insist that the design approach to a system should not try to replace human skills by technology, but attempts to support and amplify the existing human ability of making sense of situations.

Systems Support for Fire ER in the UK

Almost all the FRS organizations in the UK use several systems developed under different technologies to support their decision-making strategy (South Wales Fire and Rescue Service, 2007; Fire Service Manual Volume 2: Incident Command, 2008; West Yorkshire Fire and Rescue Service, 2007; Yang, 2006). However, most of the existing systems are focused on supporting the prevention, preparedness, and mitigation phases of a fire emergency, but not on the response phase (Yang and Frederick, 2004). Only a few FRS brigades have their own support in the decision-making process at the venue of the incident. Even these systems are only capable of providing static information, so can only provide minimal support in the dynamic decision-making requirements of the fire ground officers (South Wales Fire and Rescue Service, 2007). Recently, in the UK, there have been several initiatives to design and development of systems to support fire ER work. The following section reviews some of these.

The Fire Safety Engineering Group (FSEG) of the University of Greenwich has developed two software tools namely "SMARTFIRE" and "EXODUS." SMARTFIRE seeks to support decision-making in a fire hazards (FSEG, 2007a). It is an advanced computational fluid dynamics fire simulation environment, designed and developed as a fire simulation tool specifically for use in the very early and the later stages of the ER cycle. "EXODUS"

(FSEG, 2007b) is a suite of software tools designed to simulate the evacuation of a large number of people from a variety of enclosure types. This is useful for training firefighters and not capable of providing support during an actual fire.

“FireGrid” (Berry et al., 2005; FireGrid, 2008) is a multi-disciplinary consortium effort to develop a prototype ER system. In the event of a fire, it provides firefighters with information concerning the likely sequence of events before they occur in real-time. This project has carried out several experiments to test the feasibility of the technologies (Upadhyay et al., 2008). Upadhyay et al. (2008) also proposed a conceptual systems architecture that provides the framework for the “FireGrid” project. This project recognized the importance of providing contextual information within a building to firefighters, during a fire emergency. However, there is no evidence that this study has identified the comprehensive needs of the firefighters; rather it focused on the use of some popular technologies to support several common needs during a fire emergency.

The UK government is also directly investing in new equipment, technology and systems through its Fire and Resilience Program (CLG, 2009c) which consist of three key projects: Firelink, FiReControl and New Dimension.

The main purpose of the “Firelink” project is to provide the FRS of the UK with communication facilities necessary to mobilise resources in response to any emergency (999) call and maintain communication between the control room and incident commander (CLG, 2008a). This is a £350 million project (NAO, 2009) funded by the Department of Communities and Local Government (CLG) which will replace each FRS’s current radio technology with, a single wide area communication capability. “Firelink,” together with the “FiReControl” project will improve communications between the crew and control room and at command level between FRS, police and ambulance services. “Firelink” will be rolled out to 46 FRS head quarters in England, 8 in Scotland, 3 in Wales, and 2 fire service colleges.

“FiReControl” is a project working to reduce and centralise 46 fire control rooms to nine new Regional Control Centres (RCCs). Existing control rooms do a good job, but are not designed to deal with major regional or national incidents (CLG, 2008b). This £423 million project (NAO, 2010) requires the procurement and installation of IT hardware in 9 RCCs,

46 FRS headquarters, 1,400 fire stations and 3,400 fire engines. The heart of the project will be an information system running on this hardware, coordinating emergency mobilisation and supporting response decision-making. This system aims to control and coordinate the chain of emergency activities: from taking and identifying an incoming emergency call, to dispatching the right resources to the incident site and keeping updated with incident related real-time information.

At the beginning, these projects planned to identify the detailed requirements in consultation with FRS end-users to ensure system's design and development is aligned to end-user requirements. But these projects have faced major setbacks in identifying the detailed end-user requirements and made very little progress since its start in 2004 (NAO, 2010). There are many technical issues as the equipment and technologies acquired do not match with the actual end-user requirements (NAO, 2009).

“New Dimension” is a £330 million project (NAO, 2008) aimed to provide appropriate specialist vehicles and equipment, fund training for firefighters to use the new equipment, and support planning for deployment of the equipment to face fire ER in the new millennium (CLG, 2008c; 2009d). This includes investing in Enhanced Command Support Vehicles. These vehicles will be equipped with state of the art technologies and systems capable of supporting incident command decision-making during a response (NAO, 2008). “Vector Command”, a commercial software vendor has been invited to develop a Command Support System, an integrated technology solution for the next generation of incident command vehicles (Prendergast, 2007a; 2007b; 2009). According to Vector Command, “Command Support System” will be a product capable of looking after much needed management information requirements of different commanding officers. However, it depends on the use of historical and static information, rather than on real-time dynamic information. There is little evidence to confirm that the system will support the frontline firefighters who are close to the core of an incident. The requirement elicitation of this project appears to be based on the traditional system analysis methods and is focused on the tasks of the operators and thereby strictly limited to the technologies, methods and procedures attached to such tasks.

The literature reviewed indicates that even the recent initiatives in UK are only capable of extending some limited support to frontline responders during the response phase of a fire

emergency. Frontline firefighters are still suffering due to limited systems support for their decision-making during incidents.

All the studies reviewed under Section 2.4.1 provide useful contributions to understanding more of how to support emergency responders. In general, these recognize the importance of embedding decision-making ability in the information systems supporting various types of ER operations. The review of literature also confirms the recent interest shown in the research communities across the globe and in the UK to provide support for fire ER and other similar response work.

Most of the work reviewed related to models and architectures for ER systems concerns generic needs common to a society or community, rather than focusing on a particular emergency domain such as fire. The majority of them have not shown any interest in understanding the actual end-users information needs. Rather they are focused on a few specific needs related to a particular domain of emergency or some generic needs common to emergencies. Even the investigations carried out by the few studies that have shown some interest in end-user needs is limited to the scope of the capabilities of the technology being recommended.

More recently, system development efforts have shown a trend in the research community towards more user centered approach to their work. Also in the domain of fire ER, there are a few studies which have shown the significance of identifying responder needs prior to proposing a technological solution. However, even in most of these studies, the requirements of the responders presented are only related to the use of particular technologies. These studies have not recognized the individual differences of the needs of different types of firefighters. There is hardly any evidence that these studies have considered the views of both novice and the experienced responders during the elicitation of requirements. Also, most of these failed to recognize the need differences created by different responder job roles. Most of the human centered explorations are strictly focused on understanding either a particular need, issue, task or a job. Particularly, in the UK context, there is very little research focussed on understanding the comprehensive needs of different firefighters for the design and development of an information system.

Despite the close link between the decision-making and SA and despite recommendations of ER systems models to enhance SA of responders, only a few system development efforts have recognized the importance of enhancing SA. However, none of these studies clearly manage to define and understand SA. Furthermore, these studies did not explore how to design a system with the purpose of enhancing SA.

2.5 Situation Awareness

In the late 1980s, the focus on Situation Awareness (SA) emerged as a key cognitive construct of interest, springing from the terminology and challenges of the aviation field (Endsley et al., 2007). Situation Awareness is an operator's mental representation of the world around him, at any given time. Put simply SA is about dynamically knowing and recognizing what is going on around you (McIlvaine, 2007). It is a key factor required for moment-to-moment decision-making and performance in complex systems (Endsley, 1988). Today SA research has expanded into many other sectors like military contexts, air traffic control, nuclear & petro chemical plant operation, driving and aviation (Stanton et al., 2005; Endsley, 2000).

SA has several definitions (Stanton et al., 2005), and so approaches to SA research have a variety of theoretical ties emerging from the work of Adams et al. (1995), Durso and Gronlund (1999), Smith and Hancock (1995) and Endsley (1995). A universally accepted definition for SA is yet to emerge (Stanton et al., 2005), so it is important to describe the way this particular study uses the concept SA.

Presently two SA theories have been identified as dominant (Stanton et al., 2005). These are the three level model of SA proposed by Endsley (1995) and the perceptual cycle model of SA proposed by Smith and Hancock (1995). According to Stanton et al. (2005), most SA research uses the SA model developed by Endsley (1995). Endsley's (1995) definition of SA appears to have stood the test of time reasonably well (Wickens, 2008). It has become the most commonly used and widely cited theory in the field of SA (Albers, 1998; Stanton et al., 2005; Klein, 2000; Son et al, 2007). More importantly, the information processing approach is best represented by the Endsley's (1995) SA model compared to any other models (Stanton et al., 2001).

In her model, Endsley suggests that SA is an essential component of human decision-making, especially in complex and stressful contexts such as emergencies (Endsley et al., 2003a). SA is formally defined by Endsley (1995) as

*“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.”*

This leads to a three level model for SA as follows:

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 relevant elements in the environment. As an example, a pilot needs to perceive important elements such as other air craft, terrain, system status and warning lights along with their characteristics (Endsley et al., 2003b).

Level 2 SA: Comprehension of the Current Situation: 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 include an understanding of the significance of those elements in the light of one’s goals. The operators put together Level 1 data to form a holistic picture of the environment, including a comprehension of the significance of objects and events. For example, upon seeing warning lights indicating a problem during takeoff, a pilot must quickly determine the seriousness of the problem in terms of the immediate air worthiness of the air craft and combine this with the knowledge of the amount of runway remaining to know whether it is an abort situation (Endsley et al., 2003b).

Level 3 SA: Projection of Future Status: It is the ability to project the future actions of the elements in the environment, at least in the very near term that forms the third and highest level of SA. This is achieved through knowledge of the status and dynamics of the elements and a comprehension of the situation (both Level 1 and Level 2 SA). For example, an Army commander may have to use his experience to combine both Level 2 and Level 1 information to predict in which direction enemy troops will approach and the likely effects of their own actions (Endsley et al., 2003b).

It is important to note that although there is a significant impact on the decision-making, high SA does not always lead to better decisions (Son et al., 2007). Factors such as strategy, experience, training, personality, organizational and technical constraints may also affect

the decision-making process (Endsley and Garland, 2000). However, during emergencies, experts can make incorrect decisions due to the failures of SA at different levels (Son et al., 2007).

2.5.1 Situation Awareness and Job Related Goals

Endsley's SA model (1995) is concerned with individuals who need SA for specific reasons. For a given individual in an organizational hierarchy, SA has been defined corresponding to the goals and decision requirements that need to be achieved by that particular job.

“A pilot does not need to know everything (e.g. the co-pilot's shoe size and spouse's name), but does need to know a great deal of information related to the goal of safely flying the aircraft. A surgeon has just as greater need for situation awareness; however, the things he/she needs to know about will be quite different, dependent on a different set of goals and decision tasks” (Endsley, 2000).

The above statement clearly defines the relationship between the job related goals, decisions and SA. Goals are central to the development of SA (Endsley, 2000;2001). In what Casson (1983) has termed a top-down decision-making process, the operator's goals and plans will direct, which aspects of the environment are attended to in the development of SA (Endsley, 2000).

Goals are defined as the means of representing or capturing desires, obligations or norms, which are the primary motivations of any individual (Dignum et al., 2002).

- **Desires** are those forms of motivation, which arise internally within an individual.
- **Obligations** are directly related to other individuals, and are also typically associated with penalties that apply when they are not fulfilled.
- **Norms** are manifest in human societies and organizations and assist in standardizing the behaviour of individuals, making it easier to cooperate and/or interact within that society.

Goals are what need to be met to satisfy desires, obligations and norms of an individual.

2.5.2 Complementary and Conflicting Theories and Concepts Related to Situation

Awareness

Sensemaking

Recently there is much interest in human sensemaking in ER domains (Weick, 1988; 1995). As discussed in the section 2.4.1, several studies that promote human centered approach to design systems have focussed on sensemaking processes. However, Endsley (2004) argues that sense making is a subset of SA. According to Endsley, sensemaking is the process of making Level 2 situations from Level 1 data. Confirming this argument, Klein et al. (2006) explain that sensemaking is viewed more as a motivated continuous effort to understand connections among people, places and events to anticipate their trajectories and act effectively rather than the state of knowledge underlying SA. Endsley (2004) also argues that sensemaking is backward focused, forming reasons for past events. In contrast, SA is an ongoing model of the situation that is in place during routine as well as novel situations and typically it is forward looking, projecting what is likely to happen to inform effective decision processes (Endsley, 2004). Therefore, active sensemaking is capable of presenting only a portion of the picture of a situation (Endsley, 2004). This argument clearly indicates the danger of focusing only on sensemaking because it may miss some of the need or requirements necessary to formulate the SA..

Mental Picture

SA should not be confused with the mental picture formed by decision makers before taking their decisions; rather, the mental picture is an outcome of the process of SA and it may be considered a snapshot of the state of events at a point in time (Blandford and Wong, 2004). The mental picture, or the operator's understanding of the situation, comprises a static, structural and a dynamic, temporal component; dividing information into structural and temporal components.

Mental Models

SA differs from mental models in its emphasis on the dynamic and changing situational features that an operator must keep up with. In contrast, mental models evolve more slowly than SA, which is likely to change from moment to moment (Endsley et al., 2007).

2.5.3 Information Systems Support for Situation Awareness

During ER operations, the sources for each responder to obtain information to form SA will be different depending on specific circumstances (Son et al., 2007). However, the most important exercise is to bring together all of the incoming data from many information systems, direct observation of environment, communication with colleagues and others from related response organizations into an integrated whole (Endsley, 2001). Unfortunately, in dynamic and time-critical work environments, it is not always possible to acquire SA only by direct observation from environment (Son et al., 2007). In these conditions, information systems can play a critical role in supporting data collection, sharing, processing, communication and presentation (Son et al., 2007). However, the success of the information systems with the aim of enhancing SA of an operator working in time-critical and difficult environment, involves far more than having a lot of data (Endsley, 2001). It requires that the data be integrated and transformed into the required information in a timely manner. Endsley et al. (2003b) explain that if an information system is managed to enhance SA of its users then the design of such type of system should have taken a more user centered design approach.

2.5.4 Situation Awareness Failures

Forming and maintaining SA is a difficult process (Endsley, 2003b). Endsley (1999) argues that human decision-making failures are mainly caused by the failures in SA. At any level, SA failure has two main causes; either the limitation of the design of the systems or errors made by the end-users during information processing (Endsley, 1999). However, Endsley (1999) argues that failures in human information processing are often caused by the poor design of systems. Thus, the two main causes for SA failures are not independent. Endsley et al. (2003b) identified eight possible factors that lead to SA failures and named them as “SA Demons” (Durso and Sethumadhavan, 2008). Bolstad et al. (2006) argue that most of the SA failures are due to the use of information systems that carry various SA Demons (Bolstad et al., 2006). These SA Demons are as follows:

1. **Attention Tunnelling:** Users fix their attention only on specific elements of information while becoming blinded to other elements. In many situations, users must receive and process information from multiple sources in their surroundings while attending to several tasks simultaneously. This *attention sharing* is extremely important for maintaining adequate SA and can be lost through *attention tunnelling*.

2. **Requisite Memory Trap:** Some designs tax working memory to the point where SA is decreased due to overload. Systems that force users to remember a large amount of information can inadvertently cause a larger number of errors.
3. **Workload, Anxiety, Fatigue, and Other Stressors (WAFOS):** Psychological and physical stressors can negatively affect information intake by making it less systematic and more error prone.
4. **Information/Data Overload:** The way data is processed, stored and displayed to the users can contribute to overload. Organization and presentation are key elements affecting how well a user can absorb and process data.
5. **Misplaced Salience:** Salience is a feature of many systems used to denote important information. Salience may help or hinder SA depending on the context of use. Though salience may be used appropriately and keep the user focused on important cues, it can also mislead and confuse the user.
6. **Complexity Creep:** Complexity can often prevent users from forming adequate internal representations of how systems function. Poor internal representations can cause users to misinterpret information presented and can undermine their ability to project future events.
7. **Errant Mental Models:** Mental models play a key role in how information is interpreted, comprehended and used to make projections. An errant mental model can be particularly insidious since the user may not know that the model they are using is flawed, making the user far more error prone. This may cause end-users to misinterpret the meaning of cues. Mode errors are an especial case of this problem, in which people misunderstand information because they believe that the system is in one mode when it is actually in another.
8. **Out-of-the-loop Syndrome:** Too much automation can push the user out-of-the-loop. Highly automated systems can actually remove the user so far from the elements he or she is trying to control that the user can actually lose touch with the status of those elements.

It is vital to understand the impact of these SA Demons and minimize their impact in the process of design and development of a system (Endsley et al, 2003; Durso and Sethumadhavan, 2008; Bolstad et al., 2006).

2.5.5 Situation Awareness Oriented Information Systems Design

This section intends to explore and understand the practices that can lead to development of information systems capable of forming and maintaining better SA so that the end-users could be successful in their decision-making.

Delineating Dynamic Information Needs or SA Requirements

Before proposing an information system to support SA, it is crucial to understand what “*supporting SA*” means in a particular domain (Endsley et al., 2003b). Such understanding could be accomplished by delineating the operator’s dynamic information needs (Endsley et al., 2003a; 2003b). Thus, the user centered designing of an information system consisting of interfaces that minimize the influences of SA Demons begins with identification of the dynamic information needs or SA requirements of the operator (Endsley et al., 2003b; Durso and Sethumadhavan, 2008). In the SA model (Endsley, 1995), the dynamic information requirements associated with major goals or sub goals of an operator in performing his /her job are defined as their SA requirements (Endsley et al., 2003b; Wickens, 2008; Endsley, 2000). Without understanding the effect of goals on SA, the information presented to a person through a system has no meaning (Endsley et al, 2003b). Therefore, the ability of an information system to support decision makers in successfully accomplishing their mission depends on how well the system supports attainment of their goals (Albers, 2004).

Traditionally systems design has focused on analysis of tasks (Endsley et al., 2003b; Albers, 1998; Stanton et al., 2005). Physical tasks are actions for achieving a goal (Endsley et al., 2003b; Hoffman and Militello, 2008). Apart from physical tasks, there are also cognitive tasks. The level of success in fulfilling goals depends on the capability of the tasks used to achieve the corresponding goal. Sometimes an individual may reach their goals with only partial satisfaction due to the limitations of the tasks been used. However, dynamic information needs that represent an individual’s SA requirements cannot be accessed easily via a traditional task analysis (Endsley et al., 2003b; Albers 1998). Focusing only on tasks induces an artificial ceiling effect due to the technology, methods and processes being embedded in the task. This obscures much of the information the decision maker would ideally like to know. This approach is restrictive as it often does not identify the comprehensive information the decision maker needs to accomplish goals, nor does it identify how the decision maker integrates information to gain an understanding of

the situation (Endsley et al., 2003b). In addition, it is often assumed that work is sequential and linear, while much of SA involves a constantly changing and conflicting demand from multiple goals and processing of information in a nonlinear fashion (Hoffman and Militello, 2008). System designers can be successful by observing tasks when tasks are based on mature technologies and when such tasks can provide the maximum level of satisfaction in achieving that particular goal. Often this happens in the office environment as most of the tasks employed lead to achieving the goals with the expected level of satisfaction (Albers, 1998). Although traditional task analysis alone may be capable of identifying the information necessary to the design process of an information system in more predictable and static domains, they are insufficient to identify the informational requirements fully where decision makers are working in complex, dynamic environments (Endsley, 2003b; Albers, 1998; Hoffman and Militello, 2008).

Often, the tasks used by the emergency responders are not sufficient enough to fulfil the expected levels of satisfaction defined in the goals. Therefore, there is a possibility that although firefighters achieve their goals, their satisfaction remains low as tasks are not mature enough to fulfil the satisfaction levels attached to the goals. So studying only the tasks related to firefighters may not reveal expectations related to their SA. Therefore, in the domain of ER, there is a possibility that a study, which only focuses on tasks, will miss the end-user's needs related to the goals that cannot be achieved by the tasks, and so leads to a partial knowledge of the responder's needs.

From the literature reviewed in Section 2.4.1, it is evident that there is very little effort to understand the individual needs of different ER first responders related to their goals or desires. Rather, most of the identified needs are strictly related to the current tasks or procedures adopted by the responders.

Information Presentation

SA requirements focus not only on what information the operator needs, but also on how that information is integrated or combined to address each decision (Endsley et al., 2003b). During time-critical, complex situations such as emergencies, the way in which information is presented to the operator through interfaces influences their SA by determining how much information can be acquired in the limited time available, how accurately it can be acquired, and the degree to which that information matches with the operator's SA needs

(Endsley et al., 2003b). Therefore, presenting a mass of data will do no good unless it is successfully transmitted so that the information can be absorbed and assimilated in a timely manner by the human to form their SA (Endsley et al., 2003b). So it is important to understand how information can be presented or transmitted to the operators in a way that can enhance their SA. However, most of the previously reviewed studies in Section 2.4.1 related to supporting ER operations were predominantly interested in generating and coordination of information. There was very little work focused on the presentation of information to enhance SA of the responders.

Situation Awareness Oriented Design Principles

To ensure better systems design that is capable of meeting the requirements related to SA, Endsley et al. (2003b) proposed 50 design principles (Durso and Sethumadhavan, 2008) classified into six main categories (Bolstad et al., 2006) :

- General
- Confidence and Uncertainty
- Dealing with Complexity,
- Alarms, Diagnosis and SA,
- Automation and SA
- Supporting SA in Multi-Person Operation

However, the eight principles belonging to the General category can be considered the main principles of the guideline (Bolstad et al., 2006). The remaining 42 principles belonging to the rest of the five categories are considered as complementary principles useful to support the 8 principles in the General Category. The 8 main principles are as follows:

- 1) **Organise Information Around Goals:** Displays and Interfaces should be organised to present the information needed to support the decision-making to achieve a particular goal.
- 2) **Present Level 2 SA Information Directly (Support Comprehension):** Displays should provide information that is processed and integrated in terms of level 2 SA requirements since attention and working memory are limited. For example, directly illustrating the deviation between a current value and its expected (or required) value is better than requiring the operator to calculate this information based on the lower-level data.
- 3) **Provide Assistance for Level 3 SA Projections: Although it is often** very difficult, systems capable of generating support for projecting future events and states of the

surrounding will be capable of providing much greater decision-making support for its end-users. Although this feature is useful for both expert and novice, it will be particularly beneficial for the less experienced operators.

- 4) **Support Global SA:** Designs that limit access to information may lead to attention narrowing (Jones and Endsley, 1996). Excessive levels of menus and windows may restrict information on other windows, which carry information signalling users to attend to other information that is more important. This can be reduced by introducing displays that deliver the big picture or global SA information to the end-user. Global SA is defined as the higher-level overview of the situation across operator goals that should always be provided. Simultaneously, detailed information related to the operator's current goal of interest should be provided as required. Usually a global SA display that is visible at all times may be needed. This can be achieved by continuous delivery of a holistic overview of the situation across the end-user goals..
- 5) **Support Tradeoffs between Goal-driven and Data-driven Processing:** Designing the system around operator goals is top-down. However, to provide a holistic overview that supports the global SA will require some data driven processing, which is bottom-up. It is important to ensure these two requirement complement each other.
- 6) **Activation of Mental Models should become a Salient Feature in Information Presentation:** During complex and time-critical missions, end-users often tend to build mental models to form higher levels of SA. These mental models are activated by several critical cues or strategies. Decision-making can be facilitated if the critical attributes or features are perceptually salient (Kaplan and Simon, 1990).
- 7) **Take Advantage of Parallel Processing:** During a complex situation, it is important that the support systems are able to share attention between multiple tasks and sources of information. Therefore, systems designs capable of providing a mode of parallel processing of information to its end-users will provide higher-level of SA. Humans are capable of processing both visual and audio information in parallel. Furthermore, they are capable of processing tactile information in combination with either audio or visual information (Wickens, 1992).
- 8) **Use Information Filtering Carefully:** In most of the present day sophisticated systems, information overload is still a major problem. Therefore, careful filtering of extraneous information not related to SA needs is beneficial. It is thought that such an approach will reduce data overload and thus improve SA. Yet it must be done in an extremely careful manner as information filtering can seriously dilute and degrade the

SA capability (Endsley and Bolstad, 1993). Presenting information in a clear and easy to process manner, yet allowing the end-user to determine what they want to look and at when, would be more appropriate than the system driven strategies of delivering a subset of information.

These principles were developed based on an understanding of the factors which affect SA, especially related to the systems supporting complex and time-critical domains (Endsley et al. 2003a; 2003b). Bolstad et al. (2006) argue that using SA oriented principles in system design should minimise the SA Demons explained earlier and help to develop systems supporting better decision-making.

2.6 System Developments Based on Situation Awareness Requirements

This section discusses the existing work, which recognised the importance of understanding SA requirements during the design phase of a system.

SA in En-route Air Traffic Control: Endsley and Rodgers (1994) described the importance of having SA and defined it as one of the key aspects required for successful decision-making efforts of the air traffic controllers. The authors conducted an in-depth qualitative analysis to explore the SA requirements of air traffic controllers. They adopted a goal directed approach to identify the major goals, sub goals, decisions and associated SA requirements of the operators. This elicitation was based on interviews conducted with experienced Air Traffic Control (ATC) specialists and by observing actual operations as well as video-tapes of simulated air traffic control activities. The authors were successful in identifying the major SA requirements for en-route ATC and laying the foundation for future system development.

SA in Aircraft Maintenance Teams: Endsley and Robertson (2000) investigated the SA requirements of Aircraft Maintenance Teams (AMTs). They identified several key issues that lead to human error in the maintenance of aircraft and concluded that these errors were mainly caused by the lack of SA. The authors further highlighted the importance of identifying SA requirements before acquiring any support systems. For this particular study, the authors employed a goal directed approach to acquire SA requirements of the end-users. At the end of the study, specific recommendations were made to improve organizational wide SA, systems design and training. The authors believe that such recommendations could be applicable to a wide variety of other industrial settings. This assessment was later used as a guide to identify future systems design recommendations for

improving SA in AMTs. The evaluation feedback received for the system prototype indicated its usefulness for aircraft maintenance decision-making.

SA in Army Command and Control: Riley et al. (2006) conducted a study on complex Command and Control (C2) operation in army land-battle situations. It has been observed that C2 teams often perform their operations in contexts defined as complex, rapidly changing and uncertain (Kaempf et al., 1996; Rasker et al., 2000). Riley et al. (2006) highlighted that regardless of the domain needs it is necessary to perceive, interpret, and exchange large amounts of frequently ambiguous information to develop and maintain their SA needs. Riley et al. (2006) have defined the SA requirements as the dynamic information needs associated with major goals and sub goals of the operator in performing his or her job and selected the cognitive task analysis tool: Goal Directed Task Analysis (GDTA) (Endsley et al., 2003b) as their information elicitation tool. The authors have strengthened their requirements gathering process by reviewing military related documents and by observing field exercises. The authors also indicate the importance of understanding how the data presented through various systems and devices should be integrated or combined to make operational decisions. Thus, after collecting the SA requirements, Riley et al. (2006) introduced a design concept to support shared SA in Army Brigade C2 operations. They developed an integrated decision support display suite called “Synergy.” The design of the interfaces of the “Synergy” is based on the SA oriented design principles introduced by Endsley et al. (2003b). The end-user satisfaction at the evaluation of the interfaces indicated the appropriateness of the use of SA oriented principles in the design of the information system.

SA Applications for Executive Dashboard Design: Resnick (2003) argued that in global financial markets, and internet-based business models, executive decision-making increasingly needs speed, scope, and accuracy. The author suggests that in today’s complex business environments, executive dashboards should be designed to maximize the SA of the executives. The author also comments that the extraction of information from data sources is often driven by the user’s goals and expectations.

Improving SA in Complex Problem Solving: Michael Albers (1999) did not study a specific domain, but argued that to support complex decision-making, systems design must place the information within the context and should allow users to develop and maintain SA. Agreeing with Endsley (1995), Albers described SA as more than just awareness of numerous pieces of data. He argues that SA is about possessing an advanced understanding of the situation and a projection into the future, based on the goals of the users. Albers

stresses (Albers, 1998) that decision-making is based on the people's interpretation of information in their environment. Therefore, inappropriate or incomplete information is the main cause of poor decisions. He argues that in a time pressured environment, failures to acquire situation information may lead to failures in decision-making.

SA Support for Civil Engineers during Disasters: Son et al. (2007) presents a comprehensive framework and implementation approach to ensure effectiveness of disaster response operations. The framework ensures high SA while supporting collaboration among first responders, including improved civil engineers' roles. The study also proposed a system prototype that has focused on improving interaction between multiple individuals with an ultimate goal to improve SA in complex socio-behavioural-technical environments. Although focused on the role of Civil engineers during disasters, this work explains how a high-level of SA has the potential to enhance first responders' performance and manage the work demand resulting from distributed, dynamic, and chaotic situations resulting from a disaster in modern urban environments.

SA Oriented Design for Unmanned Vehicles: Connors et al. (2008) address the application of SA oriented design principles to the development of collaborative control interfaces. These interfaces enable small co-located or distributed teams of operators to plan and manage multiple Unmanned Vehicles (UVs) while supporting high-levels of SA. GDTA is used to capture the SA requirements for three separate unmanned systems.

SA in Emergency Medical Dispatch: Blandford and Wong (2004) described the usefulness of SA among senior Emergency Medical Dispatch (EMD) operators. They identified the work of ambulance operators who typically work under time pressure with high-risks and have to make their decisions with inadequate information. Apart from field observations and documentation, they adopted two other strategies; Contextual Inquiry Interviews (Beyer and Holtzblatt, 1998) and Critical Decision Method (CDM) (Hoffman et al., 1998) a cognitive task analysis method. Finally, authors have proposed a set of design guidelines for system displays supporting EMD operators. However, at the end, the authors comment that they could have selected or developed a different information gathering approach, specifically focusing on the SA concept. Furthermore, they believed that such an approach could have led to better findings.

All these studies highlight the difficulty and challenge of eliciting needs of operators working in time-critical complex environments, and recognise the importance of selecting appropriate approaches to discover such information. Furthermore, most of the studies

stress the importance of recognising user needs related to the end-users goals. As a part of an iterative process of design and development of an information system, most of the work produced early prototypes consisting of human computer interfaces. These prototypes are subsequently evaluated to obtain some useful feedback. Thus, these studies are based on SA oriented approaches supporting the user centered design of systems. Furthermore, almost all these studies emphasize the importance of improving SA as an essential requirement to better decision-making of operators in time-critical complex environments.

These studies provide convincing evidence to justify the argument that information systems designed with the view of promoting SA of its end-users are primarily promoting the user centered approach. Also, this section provides strong evidence to show that it is important to understand the SA requirements in the process of designing systems.. Such systems are more capable of supporting the decision-making tasks of its end-users. However, there is no significant evidence to confirm that these studies have recognized the differing needs of operators having different level of experience performing in a particular job.

Apart from the work of Blandford and Wong (2004) related to emergency medical teams and few other studies, there is hardly any previous research that focused on providing information systems support to improve SA of the operators related to ER. Furthermore, there are few studies that recognised the impact of SA related to the decision-making of emergency first responders. There is very little effort to understand the comprehensive SA requirements of individual operators who work in the ER related domains. To date there is very little empirical or exploratory work conducted related to design and development of information systems specifically in fire and rescue domain with the aim of improving SA of firefighters during their response work.

2.7 Conclusion

This chapter has reviewed the existing literature on ER, decision-making related to ER and systems support available for ER decision-making specially focused on the fire ER. It has also explored SA, a key area that is considered to have significant influence on designing better information systems. Finally, several significant systems design and development efforts based on the SA requirements were reviewed.

The review indicates that while there is a substantial body of knowledge about design and development of information systems supporting decision-making during ER, most of the efforts are focused on introducing or promoting technologies, and so take a more technology centered approach. There is a lack of user centered design of systems supporting ER decision-making. The literature confirms it is crucial to explore, identify and understand the comprehensive needs of frontline responders. Furthermore, despite recent development of information and communication technologies, the literature indicates that ER systems do not perform to meet the expectations of the responders. The review indicates that the design and development efforts of ER systems, especially related to support fire ER, lack the comprehensive understanding of individual user needs.

The literature review also indicates that there is negligible SA based research conducted in ER domains. Particularly related to the fire ER, there is a very little work on the importance of enhancing SA leading to better decision-making. Furthermore, there is no significant effort made to design an information system based on the SA oriented design approach. Thus, there is very little understanding of information needs of the individual end-users as well as their needs related to delivery or presentation of information. Consequently, it is timely for research to help fill these gaps by taking a user centric SA oriented approach to design an information system for fire ER.

The review demonstrates that the UK FRS is one of the ER organizations that have shown significant interest and investment in terms of improving systems support during fire ER operations. However, UK FRS so far has not managed to meet the expectations of supporting the decision-making of its frontline responders. The literature also indicates the limited progress made into understanding the end-user requirements. Moreover, the literature reveals there is an increase in the level of concern of UK FRS towards supporting fire emergencies in large buildings having high-fire risks. Consequently, it is argued that the UK FRS response efforts related to large built environments having higher fire risks presents an excellent research environment for a study in information systems supporting fire ER.

Chapter 3 : Research Design and Methodology

3.1 Introduction

The aim of this chapter is to provide the overall design and the methodological overview of the study. This chapter starts discussing an appropriate philosophical view and the process of adopting a suitable methodology. Then it explains the development and application of an innovative tool for gathering information requirements.. The chapter also discusses the techniques to be used to explore the deployment and presentation of information needs of the firefighters. Finally, the chapter describes the approach undertaken in the development of a conceptual information system architecture.

3.2 Research Philosophy

Research philosophy is concerned about what kind of things exists in the world and our belief towards them (Williams and May, 1996). It describes the way in which data about a phenomenon should be gathered, analyzed and used. Walsham (1995) and Garcia and Quek (1997) argue that coherent research can be conducted only through such philosophical reflection (Dobson, 2002). The importance of defining the philosophical position is emphasized by Walsham (1995) who wishes to encourage IS researchers to reflect on the basis, conduct and reporting of their work (Dobson, 2002; 2001). Walsham (1995) encourages the adoption of multiple perspectives and feels that researchers need to reflect on their philosophical stance and explicitly define their stance when writing up their work (Dobson, 2002; 2001). Yet, as described by Crotty (1998), understanding and focusing one's philosophical viewpoints is challenging due to the vast array of theoretical perspectives and methodologies. Furthermore, those challenges become daunting due to the inconsistent and contradictory nature of terminology used in the literature. To avoid such confusion, it is essential for a researcher to clearly describe his or her philosophical beliefs.

3.3 Ontological and Epistemological Views in IS research

Drawing from the epistemological beliefs of Chua (1986), Orlikowski and Baroudi (1991) classified IS research into three main categories: positivist, interpretive, and critical studies. For this study, it is beneficial to compare interpretive, positivist, or critical research before a selection is made. Often no clear distinction is made between “qualitative” and “interpretive” research and similarly between “quantitative” and “positivist” (Klein and

Myers, 1999). However, the word “interpretive” as used here is not a synonym for “qualitative” (Klein and Myers, 1999). Qualitative research may or may not be interpretive, depending upon the underlying philosophical assumptions of the researcher (Myers, 1997). To have a clear understanding, the following paragraphs explain the three main IS research epistemologies.

3.3.1 Positivism

Positivists believe that reality is stable and can be observed and described from an objective viewpoint (Levin, 1988), i.e. without interfering with the phenomena being studied. Therefore, research in the domain of IS can be classified as positivist if there is evidence of formal propositions, quantifiable measures of variables, hypothesis testing, and the drawing of inferences about a phenomenon from a representative sample to a stated population (Orlikowski and Baroudi, 1991). Furthermore, ontologically, information systems researchers who are positivists assume an objective physical and social world that exists independent of humans, and whose nature can be relatively un-problematically apprehended, characterized, and measured (Orlikowski and Baroudi, 1991).

3.3.2 Interpretivism

“IS research can be classified as interpretive if it is assumed that our knowledge of reality is gained only through social constructions such a language, consciousness, shared meanings, documents, tools, and other artefacts” (Klein and Myers, 1999). Interpretive research does not set out to test hypotheses (Rowlands, 2005), and it does not predefine dependent and independent variables (Kaplan and Maxwell, 1994). It primarily focuses on the complexity of human sense making as the situation emerges (Kaplan and Maxwell, 1994). Thus, interpretive researchers attempt to understand phenomena through accessing the meanings that people assign to them (Olesen and Myers, 1999; Rowlands, 2005; Orlikowski and Baroudi, 1991). Interpretive methods used in IS related research are aimed at producing an understanding of the context of the information system and the process whereby the information system influences and is influenced by the context (Walsham, 1993). Ontologically, interpretive information systems research assumes that the social world (that is, social relations, organizations, division of labour) is not “given.” Rather, the social world is produced and reinforced by humans through their action and interaction. Organizations, groups, social systems do not exist apart from humans, and hence cannot be apprehended, characterized and measured in some objective or universal way. Unlike the

premises of the positivist perspective where researchers are presumed to “discover” an objective social reality, interpretive researchers believe that social reality can only be interpreted. (Orlikowski and Baroudi, 1991).

3.3.3 Critical Inquiry

IS research can be classified as critical if the main task is seen as being one of social critique, whereby the restrictive and alienating conditions of the status quo are brought to the light (Klein and Myers, 1999). Ontologically, within the critical philosophy the main belief is that the social reality is historically constituted. Therefore, the human beings, organizations, and societies are not confined to existing in a particular state (Chua, 1986). Another important belief of critical philosophy is that of totality.

3.4 Discussion and Rationale for the Philosophical Approach

No single epistemology is intrinsically better than any other (Orlikowski and Baroudi, 1991). All three epistemologies have their own uniqueness, strengths and weaknesses, (Bolan and Mende, 2004). Orlikowski and Baroudi (1991) explained that all three of the research philosophies can offer an insightful perspective so that over-riding concern of this discussion is to select the most appropriate philosophy for the problem being investigated in this particular research.

Since interpretive research can help IS researchers to understand human thought and action in social and organizational context, it has the potential to produce deep insights into information systems phenomena including the management and development of information systems (Klein and Myers, 1999). This study intends to answer the questions: *What are the information requirements of different role players in the fire fighter hierarchy for improving situation awareness during high-risk fire emergency?* and *How can this information be shared, presented and delivered to different role players via an appropriate information system?* These research questions justify the need of an interpretive study as they do not indicate any requirements of quantifying or defining any dependent and independent variables (Kaplan and Maxwell, 1994). The research questions focus more on the complexity of human sense making as the situation emerges (Kaplan and Maxwell, 1994). This study will also attempt the difficult task of accessing other people's interpretations, filtering them through their own conceptual apparatus, and feeding a

version of events back to others (Walsham, 1995). This study it is not intended to report the facts; instead, it is expected to interpret other people's interpretations (Walsham, 1995) and to establish credibility, this study is intended to describe in detail how it arrived at the “results” (Walsham, 1995). Hence, this study can be classified as following the interpretive epistemology.

Interpretive research is not necessarily qualitative, but the qualitative nature of this study is clear as the research questions are open-ended, evolving and non-directional. They tend to address “What” and “How” and therefore, show clear signs of qualitative research (Creswell, 1998). This study will try to understand phenomena and explore things through the eyes of firefighters representing various fire and rescue related job roles. Therefore, data gathering and analysis instruments of this study will be more qualitative than quantitative. Hence, qualitative driven interpretive philosophy is identified as appropriate to carry out this particular research.

3.5 Research Methodology

Having decided on the epistemological beliefs of the study, the next step is to identify the research methodology and data gathering instruments. Because of the diversity in qualitative instruments, many authors have tried to provide various taxonomies or categories of different qualitative methodologies. Patton (2002) has classified qualitative research into ten orientations based on the kind of questions researchers from different disciplines might ask. Creswell (1998) has identified four “traditions” namely phenomenology, grounded theory, ethnography and case study. Crotty (1998) described eight methodological approaches for qualitative research; experimental, survey, ethnography, phenomenology, grounded theory, heuristic inquiry, action research and discourse analysis (Gray, 2004).

Cassell et al. (2005) suggest classifying such methods according to the level of analysis; individual, group or organizational and then identifying a suitable methodology for each level. The research presented in this thesis predominantly focuses on exploring information requirements of FRS. Furthermore, it will be limited to several key members of the hierarchy under the influences of organizational expectations and goals. Within such context, this particular research can be classified at the level of organization analysis. From

those approaches explained in the previous section, five qualitative research approaches: Ethnography, Case Study, Grounded Theory, Action Research and Phenomenology are identified as suitable for organizational level analysis.

The comparisons made in light of the research aims and the scope of this study described in Chapter 1 suggest that ideally the best way to achieve the objectives of this research is via ethnography research with in-depth participatory observation. Ethnographers immerse themselves in the life of people they study (Lewis, 1985). It was developed by anthropologist specifically to study human society and culture (Merriam, 2002). Ethnography is also a methodology whereby multiple perspectives can be incorporated in systems design (Holzblatt and Beyer, 1993). Despite such benefit, when consider the scope of this research described in Chapter 1, ethnography research becomes impossible as a methodology where time becomes a major constraint during a study (Myers, 1999). Furthermore, pure ethnography would be unrealistic due to the lack of accessibility to observe real fire emergencies.

Action research has been identified as a methodology, which encourages system development efforts to be carried out with in-depth collaboration of the end-user or client (Susman and Evered, 1978). According to Rapoport (1970), one of the most cited definitions (Myers and Avison, 2002); action research aims to contribute both to the practical concerns of people in an immediate problematic situation and to the goals of social science by joint collaboration within a mutually acceptable ethical framework. Some researchers position action research as a subset of case study research (Benbasat et al., 1987; Galliers, 1992), but others (de Vreede, 1995) observe the differences between the two approaches and thus appear to suggest that they should be treated as separate methods. In the domain of information systems there seems to be increasing interest in action research (Myers and Avison, 2002; Baskerville and Myers, 2004). However, there are several practical constrains, which prevent this study from selecting action research as a methodology, since the participation of end-users may be limited to having interviews and discussions. Yet, considering its important characteristics towards qualitative research, effort will be made to ensure that the flavour of action research coexists with the principle research methodology to be selected.

Grounded Theory (GT) has been identified among interpretivists as a research methodology that seeks to develop theory that is grounded in data, systematically gathered and analyzed (Myers, 2009; Orlikowski, 1993; Urquhart, 2002; Martin and Turner, 1986). As an interpretive methodology, grounded theory has become a popular methodology in the domain of IS (Urquhart, 2001; Urquhart and Fernandez, 2006; Jones and Hughes, 2003; Myers and Avison, 2002; Baskerville and Pries-Heje, 1999). Since this study is not interested in developing a theory towards building a hypothesis, pure grounded theory may not be the best methodology for this particular research. Yet, as described among most other qualitative research approaches, grounded theory is popular for its data sampling and analysis techniques. Therefore, such techniques will be used whenever it is appropriate during the progress of this study.

In the same way that ethnography focuses on culture, a phenomenological study focuses on the essence or structure of an experience (Merriam, 2002). To understand the essence or structure of an experience, the researcher temporarily has to forget or “bracket,” personal attitudes or beliefs about the phenomena being investigated (Patton, 2002). Furthermore, a phenomenologist attends more actively to the participant’s views as he/she is prepared to be surprised and awed. This open stance of Phenomenology has been highlighted by Dahlberg et al. (2001).

The philosophical beliefs of this study show some similarity with the approach of Phenomenology research. Previous research efforts in the domain of emergency related systems development have been restricted by the prior technological beliefs. This would inhibit exploring the world of fire and rescue members directly, and so may miss most of the important requirements. This particular study will seek to avoid such pit falls. Thus, this study will attempt to improve the phenomenological aspects by introducing a theoretical framework to help participants express their world as directly as possible independent from preconceived technology.

Case Study methodology is the most common qualitative method used in information systems (Orlikowski and Baroudi, 1991; Alavi and Carlson, 1992). Earlier in the field of IS the qualitative case study approach was accepted as a positivist research methodology (Myers, 1999). But later, after the significant work done by Markus (1983), Boland and Day (1989), Orlikowski (1991), Walsham (1993) and Walsham and Waema (1994),

qualitative case studies based on the interpretive epistemological stance have become a well-known research approach in the domain of IS Walsham (1995).

A case study is an intensive description and analysis of a phenomenon or social unit such as an individual, group, institution or community (Merriam, 2002). In the domain of IS, drawing from several other sources (Stone, 1978; Benbasat, 1984; Yin, 1984; Bonoma, 1985 and Kaplan, 1986), Benbasat et al. (1987) have defined a case study as research methodology capable of examining a phenomenon in its natural setting, employing multiple methods of data collection to gather information from one or a few entities (people, groups or organizations). Benbasat et al. (1987) argues that case study as a methodology is appropriate where:

- It is necessary to study the phenomenon in its natural setting.
- The researcher can ask “how” and “why” questions to understand the nature and complexity of the processes taking place.
- Research is being conducted in an area where few, if any, previous studies have been undertaken.

As a research methodology, case study implies comprehensive and intensive study of the subject. In-depth investigation is thus one of the major pre-requisites. Information must be ascertained from organizations and then later carefully interpreted. These facts may be gathered from documents, archives, and especially from interviews with any person who has knowledge of the subject area (Benbasat et al., 1987). In addition, observations by the researcher, participant-investigator interaction, as well as physical artefacts can be utilized to strengthen the facts gathering and analysis (Benbasat et al., 1987; Yin, 2002). Often other types of research methodology are combined with the case study methodology (Merriam, 2002). According to Yin (2002), ethnographies usually require a long time in the field and emphasize detailed, observational evidence. In contrast, case studies are a form of enquiry that does not depend solely on ethnographic or participant-observer data (Klein and Myers, 1999). According to Benbasat et al. (1987), case study research method is particularly well-suited to IS research, especially when the research interest is into organizational rather than technical issues. This study aims to elicit the user requirements independent from any technology. Hence, the Case Study Methodology is appropriate to conduct this particular type of research.

Having considered the strengths and weaknesses of various qualitative methodologies, the qualitative case study methodology and its data gathering techniques are selected for this study. Although Ethnography and Action Research are also identified as appropriate, it will be infeasible to adopt such methodologies directly. However, this study will always look for opportunities to make observations as close as possible to the incident site and to the members being investigated. Therefore, this research will draw on the strengths of ethnography and action research methodologies wherever possible. It will also draw on the sampling and data analysis techniques associated with the grounded theory approach, and **will draw** on the flavours of Phenomenology whenever possible. The careful mixing and adoption of qualitative methodologies is expected to reduce the limitations embedded in case study research (Yin, 2002; Lubbe, 2003).

3.6 Data Gathering and Analysis Techniques

This particular research is targeted to support the requirements gathering and design of a suitable information system leading to enhance SA (Endsley, 1995) of the firefighters. Hence, the search for suitable data gathering and analysis tool could start from the investigation of the domain of requirements gathering.

3.6.1 Requirements Elicitation

The requirements elicitation process is considered to be one of the most crucial processes of the software development cycle. It is found in several previous studies that the requirements engineering phase is the source for the majority of the detected software code errors (Basili and Perricone, 1984; Jones, 1994). Robinson and Elofson (2004) argue that the existing techniques still have limitations in capturing and defining user requirements. To overcome such difficulties, techniques like Rational Unified Process, KAOS (Dardenne et al., 1991; Kruchten, 2000), Scenario Based Approaches (Weidenhaupt et al., 1998) and Goal Directed Analysis with Use Cases (Robinson and Elofson, 2004) were introduced. Ignoring the traditional systems view, Checkland (1999) has also proposed a generic system development model called Soft System Method, which considers that the view of the end-user is far more important for success in systems development.

Highlighting the shortcomings in the domain of requirements engineering, socio technical concepts such as Human Factors (HF) and Human Computer Interaction (HCI) describe the

need of having information systems design methods capable of capturing human centered requirements rather than system centered (Eason, 2001). As explained in Chapter 2, when the end-user environment becomes dynamic and ad-hoc vulnerability of requirement elicitation techniques that come under the generic software engineering literature is far greater (Albers, 1998; 1999; Endsley et al. 2003b). Therefore, the requirements elicitation process of an information system to be used in a complex and difficult environment such as a fire emergency should be centered on its end-users.

HF concepts are often used interchangeably with the concepts in the domain of HCI (Stanton et al., 2005). There is a significant overlap in these two disciplines. However, HFs generally refers to design of hardware while HCI refers to design of software (Stanton et al., 2005). As the overlap of these two communities is considered to be complementary, HFs methods techniques and approaches are being frequently complimented in the field of HCI (Stanton et al., 2005).

To avoid fatal catastrophes, the end-user of an emergency response system may have to take the correct action, right at the outset since there may not be enough time or opportunity for a second choice (Jennex, 2007; Roth et al., 2002). Developing such complex information system, it will be essential to adopt a method capable of capturing correct user requirements (Endsley et al., 2003b; Jennex, 2007). As explained in Chapter 2, User Centered Design (UCD) is capable of shifting the emphasis on design from mastery to usability by moving away from “telling people what they should use” to “understanding what they need.” Users express their needs and desires to researchers, who then translate them into practical solutions for designers and engineers to carry out the implementation. Therefore, when it comes to the designing of systems for complex and difficult domains, UCD approach is preferred to the Technology Centered Design approach (Endsley et al., 2003b).

For requirements elicitation, UCD approach encourages both quantitative and qualitative methods such as user surveys, interviews, observations, document analysis, task analysis (Maguire, 2001a) and many more. Central to the design of user centered system is a clear understanding of what users actually want to do: *What are their tasks?* and *What is the nature of those tasks?* (Crystal and Ellington, 2004).

3.6.2 Task Analysis Approaches

Task analysis played a critical role in the development of training and systems design for the past 100 years (Stanton et al., 2005). It involves identifying tasks, collection of task data, analyzing the data so that tasks are understood, and then producing a documented representation of the analyzed tasks (Annett et al., 1971). Task analysis has potential application at each stage of the systems design and development process (Kieras, 2004; Rouse et al., 1987; Crystal and Ellington, 2004).

There are a number of different approaches to task analysis available for the practitioners (Crystal and Ellington, 2004). However, it is argued that traditional task analysis techniques are not adequate to understand the human needs that have high elements of cognitive complexities (Militello and Hutton, 1998; Stanton et al., 2005). Traditional task analysis techniques are often criticized for being technology centered where systems designs based on such techniques force users to adapt to the system (Hoffman and Militello, 2008). Therefore, at present contemporary task analysis that promotes the design of more user centric systems is emerging (Hoffman and Militello, 2008). It consists of a range of techniques aimed at obtaining descriptions of what people do, representing those descriptions, predicting difficulties and evaluating systems against functional requirements (Jordan, 1998; Hoffman and Militello, 2008). A new generation of task analysis is commonly known as the Cognitive Task Analysis (Hoffman and Woods, 2000; Roth and Woods, 1989; Schraagen et al., 2000). Cognitive Task Analysis is capable of helping researchers to explore cognitively complex environments to understand human needs in the real-world context to design better systems (Hoffman and Militello, 2008).

3.6.3 Cognitive Task Analysis

“Cognitive Task Analysis” (CTA) refers to both the general process of conducting of requirements gathering (Chipman et al., 2000) and an explicit set of knowledge elicitation techniques. CTA is often referred to as a “Practitioner’s Tool Kit” (Cooke, 1999). Included in this tool kit are methods that elicit knowledge, facilitate data analysis, and those that represent the content and structure of knowledge (Crandall et al., 2006). According to Kirwan and Ainsworth (1992), CTA is defined as the study of what an operator (or team of operators) is required to do in terms of actions and/or cognitive processes to achieve a system goal. Traditional task analysis techniques often fail to consider the cognitive processes associated with the activity (Endsley, 2003b). Therefore, CTA is recognized as an

essential tool for the system designers, where analysis of the cognitive demands associated with the end-user operations becomes important (Stanton et al., 2005; Chipman et al., 2000; Jonassen et al., 1999; Clark et al., 2008).

A wide range of CTA tools such a Critical Decision Method (Klein et al., 1989), Critical Incident Technique (Flanagan, 1954), Cognitive Work Analysis (Vicente, 1999), Applied Cognitive Task Analysis (Militello and Hutton, 1998) and Goal Directed Cognitive Task Analysis (Endsley et al., 2003b) have been developed over the last 20 years (Stanton et al., 2005; Clark et al., 2008).

CTA techniques present challenges to the analysts (Crystal and Ellington, 2004). CTA requires deep engagement with a particular knowledge domain, working closely with Subject-matter Experts (SMEs) to elicit their knowledge about various tasks (Chipman et al., 2000). Therefore, a variety of Meta methods such as interviews, observation, ethnography and contextual inquiry are of value as analysts must seek to define a coherent knowledge (Crystal and Ellington, 2004). More than 100 types of CTA tools and corresponding techniques are currently in use (Clark et al., 2008). This causes difficulties for a novice practitioner to choose the most appropriate (Cooke, 1994). Mostly accessed by the knowledge engineers, cognitive psychologists and human factors/ergonomics professions, only a few CTA instruments are accessible and become popular among social researchers, training practitioners and information system designers (Militello and Hutton, 1998).

3.6.4 Selection of Appropriate CTA Tool

In selecting CTA suitable for this study it is important to consider relevant implications caused by the research objective, the research scope and the context of this study. The following specific implications are identified as important to consider during the selection of CTA tool/s.

- The gap between the expected output after an application of the selected CTA tool and the expected output for the objective (information requirements).
- The ability to explore SA related issues.
- Given the limited accessibility to the SMEs and preserving precious time of contact; ability of maximizing the use of contact hours with the SMEs.

- Given the limitation of available human resources to conduct the research; level of resource requirements to administer (Time, Labour and other physical resources) and amount of training required prior to application.
- The capability of applying in emergency related context, specifically in the context of fire emergencies.
- In relation to the researcher who conducts this particular research is neither a specialist in knowledge engineering nor cognitive psychology but only a specialist in information system designing; suitability to be used by the researcher and clarity in the steps of application and data analysis.

The selection of the most appropriate CTA tool is based on the findings of the following studies:

- The work of Stanton et al. (2005) identified the strengths and weaknesses of popular CTA tools.
- A survey: *Cognitive Engineering Methods and Systems Engineering Uses*, conducted by the MITRE Corporation (Bonaceto, 2003; 2004; Bonaceto and Burns, 2007) have evaluated the applicability of various CTA tools.
- A web portal: *CTA Resource (CTA Resource, 2006)*, which explains the strengths and weaknesses of CTA tools and techniques in various application settings.

Among the available CTA tools, techniques of both Applied Cognitive Task Analysis (ACTA) (Militello et al., 1997; Militello and Hutton, 1998) and Goal Directed Cognitive Task Analysis (GDTA) (Endsley et al., 2003b) are identified as more suitable to conduct this particular research (Prasanna et al., 2009; Yang et al., 2009a). The output of both ACTA and GDTA is recommended as useful for the design and development of an information system supporting cognitively complex domains including emergency response. ACTA was originally developed to understand the needs of firefighters having different levels of experience, while GDTA was exclusively developed with the aim of developing systems that support the operator's SA in the Aviation and the Military domains. Both ACTA and GDTA are less intensive in labour and resources than most of the other CTA instruments. Both tools do not require extensive training to conduct. Finally, techniques of both ACTA and GDTA can be used by system designers rather than knowledge engineers, cognitive psychologists or professionals in ergonomics.

3.6.5 Comparison of GDTA and ACTA

As explained in Chapter 2, this study recognizes the importance of understanding the SMEs requirements related to their operational goals rather than their tasks. Goals are cognitively demanding means of representing or capturing desires, obligations or norms, which are considered to represent primary motivations of an individual (Dignum et al., 2002). In contrast tasks are actions of achieving a goal (Endsley et al., 2003b; Hoffman and Militello, 2008). GDTA is clearly driven by the operator goals. ACTA also aims to elicit cognitively demanding requirements related to the end-user's performance (Militello et al., 1997; Militello and Hutton, 1998) and its output often take the form of goals. So both ACTA and GDTA are recognized as capable of analyzing the cognitive activities (Prasanna et al., 2009). The main difference of ACTA is that it defines the cognitive requirements as the *cognitive demands* where as GDTA defines it as the *goals*.

The output of GDTA is always capable of providing information requirements leading to make better decisions that help to achieve user goals. In contrast, ACTA is only capable of providing the cognitive demands. Therefore, output of GDTA can be considered equivalent to the actual information requirements. However, the "Cognitive Demand Table," which is the output of ACTA, needs further processing to obtain the actual information requirements.

There is hardly any evidence to indicate that ACTA being applied with the aim of developing information systems. Comparatively GDTA is exclusively designed for gathering information requirements in complex environments with the aim of designing information system interfaces (Endsley et al., 2003b).



Figure 3.1: Steps of the GDTA

As shown in Figure 3.1, the steps of GDTA are clear and ordered. Therefore, in the exercise of obtaining information requirements, users of the tool have to first visualize the goals, followed by the decisions to achieve such goals and finally the information needs to make those decisions.



Figure 3.2: Steps of the ACTA

In contrast, as shown in Figure 3.2, the ACTA steps are complex and less clear in integration. According to ACTA literature (Militello et al., 1997; Militello and Hutton, 1998), three different techniques: Task diagrams, Knowledge Audit, Simulation Interview are integrated to obtain its final output: “Cognitive Demand Table.”

Although, ACTA theory clearly defines its techniques and details of carrying out each of the three steps, it does not indicate any order or how to relate or combine the results of each step to obtain its final output. The ACTA literature explains the recommended techniques such as simulations, interviews and observations to carry out each of the three preliminary steps in a more elaborative and informative manner than GDTA. Therefore, during its application a user will find it much easier to administer the steps of ACTA than GDTA. Currently, in the UK, simulations form the basis of the firefighter training, but efforts are made to ensure these are as realistic as possible. Therefore, described as the core part of ACTA, the use of scenarios during the simulation interviews is a much more appropriate interviewing technique with firefighters than prompting them with the use of only “why” and “how” probes which are the main probes of the GDTA interviews.

3.6.6 Limitations and Constrains of GDTA and ACTA Corresponding to this Study

1. Ambiguity may creep in by asking the question “what are the goals” to reveal the goals, because SMEs in the FRS are not used to their goals but tasks. There is a risk that answers of SMEs may end up only describing their physical tasks. To overcome such limitations, GDTA recommends interview probes containing the question “why.” According to GDTA theory, it is advised to carry iteration via further interviews, observations and investigation of documentation until goals are revealed. With GDTA a user may require too much iteration before it elicits the satisfactory goal structure. This has not been a major issue so far since GDTA was used in almost all the previous occasions in a context where there was some existing support of an automated IS. In

such a context, unstructured nature of interviews with simple ad-hoc probes may not have caused a major problem as participants response was focused around the strengths and weaknesses of the support system available. However, the context considered in this study has almost no support of an existing information system so unstructured interviewing guided by simple ad-hoc probes is not recommended for this study.

2. According to the current GDTA practice, it is recommended to develop an *approximate* or *rough* goal structure as early as possible in the interview process. Thereafter with the use of such incomplete goal structure the user is required to elicit the decision and information requirements and in parallel improve the goal structure iteratively. Investigation of all three sectors during a single session of unstructured interview may lead to loss of vital data either related to goals, decisions or information.
3. With weak interview probes and unstructured interviews, GDTA allows interview sessions to float with the hope of discovering the goals after a maximum of 10 interviews. This may become a bottleneck as the interviewer has no control over the discussions and the precious contact time with the SMEs may be wasted.
4. This study defines a SME as an officer who is qualified to take the responsibility of a particular job role. Thus, SMEs belonging to a particular job role can be placed in a continuum of Novice SME to Experienced or Expert SME. Whether an operator is a novice or an experienced, ideally a system should provide good support to all the operators who are qualified to perform in a particular job (SMEs). Ignoring the level of experience of SMEs may create unnecessary bias. This may lead to inaccurate or incomplete elicitation of information requirements. GDTA does not consider the level of experience and does not indicate the necessary criteria for selecting the SMEs for the interviews.
5. The final output of the ACTA is only capable of providing the cognitive demand table. Thus, this study will need to extend the obtained cognitive demand table to the level of the information requirements. However, ACTA theory does not provide guidance on such an extension.
6. ACTA does not clearly define how to integrate the findings of Task Diagrams, Simulation Interviews and Knowledge Audit to elicit cognitive demands. This brings ambiguity to the process and may lead to an unacceptable level of subjectivity in the exercise of interpreting cognitive demands.

Although both GDTA and ACTA have significant capabilities, their limitations related to this study lead to the conclusion that the independent use of either GDTA or ACTA is not

appropriate and therefore, is not recommended as a means of capturing the information requirements of firefighters (Prasanna et al., 2009).

3.6.7 Development of an Alternative Tool: Goal Directed Information Analysis

Having considered the limitations corresponding to the independent use of ACTA and GDTA, a proposal is made to develop an alternative CTA tool. This alternative tool will be suitable to apply in an emergency domain such as fire and rescue. Therefore, amendments are proposed to combine the strengths of the techniques of both GDTA and ACTA so that the combination can form a better tool to address the requirements gathering. This alternative tool aims to capture the information requirements that facilitate the decision-making with a view of achieving the expected goals. Therefore, this alternative tool is named as the “Goal Directed Information Analysis” (GDIA) (Prasanna et al., 2009). GDIA is based on relevant scenarios and considers tasks and knowledge differences of SMEs in the process of identifying the goals. The application steps of GDIA form a solid “framework” (Ritchie and Spencer, 1994) in reaching the objective of “elicitation of information requirements of firefighters” and its Meta methods will maintain the methodological approach selected for this study.

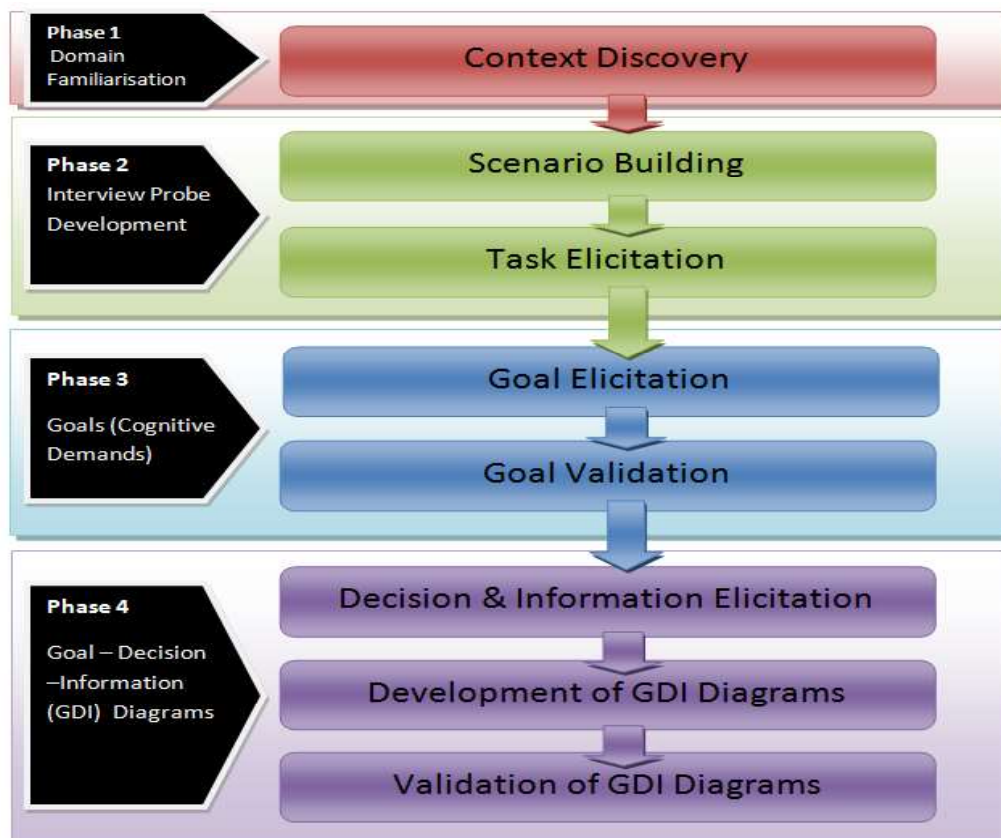


Figure 3.3: Steps of Goal Directed Information Analysis (GDIA)

The techniques proposed for GDIA will reduce the risk of non elicitation or misinterpretation of information requirements. GDIA will support the systems designers who are new or not familiar to use complex CTA tools by maintaining less complex application steps and a clear guideline supported by the appropriate use of Meta methods. Following paragraphs discuss the key steps of the proposed tool GDIA (Figure 3.3).

Step 1: Context Discovery: Initial understanding of the context being investigated is achieved via a few face-to-face discussions with SMEs, observation of real-time practices and training. Documentation such as procedure manuals and policy documents produced as a part of the emergency response work is also included for the investigation (Hammersley and Atkinson, 1995). This initial understanding is crucial as it helps to identify the important job roles to conduct the explorations and to build suitable fire scenarios, which are treated as a guideline for the second stage of the application of GDIA.

Step 2: Scenario Building: Suitable scenarios are introduced during the interview sessions to overcome the limitations due to the unstructured nature of the interviews. Scenarios are used to probe and challenge the mental models, thought habits, and unrecognized assumptions of the SME's. This enhances the interview focus as well as the imagination of the SMEs during the interviews to seek insights into context being investigated. Scenarios should be modified appropriately to cover the expected scope of the incident under investigation.

Step 3: Identifying Tasks: This involves spending time with the SMEs representing each job role and having a discussion on each scenario to clarify any confusion. Thereafter each selected SME is asked to:

- Describe the possible activities they carry out corresponding to each scenario.
- Identify possible task groupings, among the activities set out above.

This should be carried out by conducting face-to-face semi-structured interviews with the selected SMEs. During this step, scenarios are expected to expand the mental models during task identification so that SMEs may neither miss any important tasks nor describe irrelevant tasks. An appropriate number and combination of SMEs should be selected from each job role, depending on the resources and level of accessibility. To avoid any bias and to capture complete and accurate requirements, equal opportunity for both experienced and

novice SMEs should be maintained. Observations related to training sessions and references made into relevant documentation can be used to strengthen the interview findings. After data are collected, they are analyzed to develop the task structures relevant to each job role. They are used as the specific interview probes of the next step.

Step 4: Obtaining Sub goals and Goals: Semi-structured interviews are conducted with the SMEs representing both novice and experienced, (preferably with the same SMEs who described the tasks) to identify the goals and sub goals. With the previously captured task structures, the interviewer would be able to ask specific questions: *Why do you want to carry out the task x, y,...?*, *Why do you think tasks x, y..... are important?* Just before the start and in the middle of an interview, the scenarios used for the task identification are used again to maintain the mental focus of the SMEs. A combination of both scenarios and tasks improve the structure of the interview. This step concentrates only on acquiring goals and sub goals. There should be no attempt to overload the session by gathering information related to decisions and information requirements. A goal and sub goal structure representing a particular job role is developed by summarizing the interviews of different SMEs.

Step 5: Validation of the obtained Goals and Sub goals: It is a challenge to reflect the difference between a goal and a task in a written interpretation (Endsley, 2003b; Albers, 1998; Hoffman and Militello, 2008). Therefore, there is a risk that goals can be misinterpreted as tasks or tasks misinterpreted as goals in the initial goal structures. Also, there is always a risk of losing some of the data during the initial analysis phase. There can also be terminology mismatches or inconsistencies across goal structures. Thus, there is a significant risk that the goal structures developed initially could carry significant errors or be incomplete. However, it is very important to make sure that the goal structures are meaningful, accurate and complete enough to use as the interview probes in the information capturing phase. Therefore, it is essential to check the validity of the goal structures. The validation process included the following steps:

- Distribute the initial goal structure among the interviewed SMEs.
- Carry out a brainstorming session with the previously interviewed SMEs or meet SMEs individually and revisit the goal and sub goal diagrams to minimize initial anomalies.
- Validate interview findings by having discussions with different SME's who represent other relevant organizations of the county or region where the interviews are conducted.

Validity of the interview findings is further enhanced by having discussions with the SMEs representing other counties. This improves the validity of the interview findings so that they represent generic goals of the domain being investigated.

- Modify the goal and sub goal diagrams based on the comments and suggestions.

Step 6: Obtaining Information Requirements: A series of semi-structured interviews should be carried out with the SMEs for the second time by making use of the previously validated goals as probes and supported by the pre-developed scenarios. At first, with the support of goal probes, SMEs are requested to describe decision-making related requirements need in the process of achieving each and every individual goal or sub goal.

As explained by Klein et al. (1997) it is a challenging task to elicit the actual decisions that are made rapidly in cognitively demanding complex conditions. What is more important at this step is to identify relevant probes, which represent the underline decisions, so that they could be subsequently used to identify the comprehensive information needs of the SME. The above argument is supported by Endsley et al. (2003b) and Jones and Endsley (2005); according to them, decision-making requirements captured with the application of GDTA could take the form of problems or questions related to the underline decision. Immediately after the discovery of decision requirements SMEs are further probed, requesting them to describe information requirements to make such decisions. Apart from the interview data careful analysis of various field observations and fire and rescue document references can be used to further strengthen the findings. The information requirements obtained are classified according to the three tier SA classification of Endsley (1995). Finally, the Goal-Decision-Information (GDI) diagrams are drawn for the job roles studied.

Step 7: Validation of the obtained Goal – Decision – Information (GDI) Diagrams: To ensure that the GDI diagrams obtained are complete and meaningful, they are validated with a larger group of SMEs. At first the diagrams are sent to the SMEs who participated in the information gathering interviews with the instructions on how to interpret them along with a request to identify any missing information or errors Thereafter, the diagrams are distributed among suitable SMEs who are nonparticipants, employed in organizations inside as well as outside the county being investigated. Later, the feedback obtained from various sources of validation is integrated. Such integrated feedback is then used to make the necessary modifications to the GDI diagrams developed. The resulting GDI diagrams

are expected to be much more accurate, complete and more general after embedding such integrated feedback.

3.6.8 General Considerations

Although voice recording of interviews is not recommended by the GDTA approach, it is an accepted and well-known practice in the process of interviewing (Patton, 2002). Tape recording is considered as an appropriate supplement for the cases consisting of relatively non-confidential material and particularly for interviews containing a large amount of relatively “hard” data, which is difficult to capture by taking notes alone (Walsham, 1995). In this study, taking down notes and having discussion together at the same time by a single interviewer is impossible and this study has no intention to access any personal or confidential data. Therefore, tape recording is recommended as an essential element of the proposed approach.

3.7 GDIA Meta Methods

It is important to identify the appropriate Meta methods required for the implementation of each step of the GDIA. These methods are classified in to three broader classes of:

- Sampling Methods for selection of a case and selection of SMEs for the interviews.
- Data Collection Methods for eliciting information requirements.
- Data Validation Methods for the phase wise findings of GDIA.
- Data Analysis Methods for eliciting information requirements.

3.7.1 Sampling Method for Case Selection and Selection of SMEs

Many variations of qualitative sampling make sampling a very complex issue in qualitative research (Coyne, 1997). Patton (2002) and Coyne (1997) describe all sampling in qualitative research as “Purposeful Sampling.” The power of purposeful sampling lies in selecting information rich cases for an in-depth study (Patton, 2002).

After careful evaluation of various purposeful sampling strategies, “Convenience Sampling” (Patton, 2002) is selected for identifying the main source of information gathering. Although criticized by Patton (2002) as least strategic, Patton (2002) himself defined this as the most commonly used qualitative sampling strategy. According to Patton (2002), the strategy of “Critical Case Sampling” would have been the most ideal type of

sampling strategy. A metropolitan area like London could have been the best choice if selected according to the critical case sampling strategy. Yet, for this particular study, accessibility to the resources belonging to the selected case is considered to be utmost important. First, it requires extended accesses to the firefighters, training centers and locations. Second, this study requires access to the high-risk fire sites within the boundary of selected case. Due to the unpredictable work patterns and health and safety issues, access to firefighters and access to observe their activities is extremely difficult. Here, it will be important to select a FRS brigade/s for which the researcher would be able to obtain access to the firefighters as well as to the high-risk sites belonging to the service area of that brigade, so selecting the strategy of convenience sampling makes more sense.

Furthermore, in selecting secondary cases for validation and generalization of the primary findings, “Convenient Sampling” strategy is again proposed. In the validation phase of this study, it is important to find high-risk sites having similar characteristics of the primary case. In this exercise, a strategy of “Confirmatory Cases” (Patton, 2002) is ideal as it allows testing ideas confirming the importance and meaning of possible patterns elicited at the primary source and checking out the viability of emergent findings with new data and additional cases.

A mix of “Homogeneous Sampling” (Patton, 2002), “Snowball Sampling” (Patton, 2002) and “Theoretical Sampling” (Strauss and Corbin, 2008) is proposed to identify suitable SMEs to participate as information providers and validators. Homogeneous sampling involves selecting a particular sub group of SMEs where different kinds of participants exist. This strategy will identify appropriate SMEs belonging to a particular job role to be studied. Furthermore, it allows identifying the sub groups within a group. On the other hand, “Snowballing” creates opportunities to access the most suitable SMEs for a particular type of interview or a discussion. For example, this will help to identify the firefighters who are most familiar or have more experience related to the sites described in the scenarios. Furthermore, it will support the selection of the secondary sources of information as there is a greater possibility that SMEs in one FRS can provide or obtain accessibility to similar SMEs in other FRS. The decision of selecting various types of additional sources are based on the “Theoretical Sampling” strategy. According to Coyne (1997), “Theoretical Sampling” also belongs to the family of purposeful sampling. Although this study is not grounding a theory, it complements some aspects of the grounded theory. The data

collection effort is divided into clear phases of interviewing and validation. Importantly in-between these phases, findings of the previous phase are considered as an important input to conduct the next phase. Such phase wise intermediate analysis of data shows some similarity towards data gathering and sampling steps of the grounded theory based research. Therefore, the findings obtained from an intermediate analysis of data could guide or indicate the characteristics of the data gathering sources suitable for the subsequent phases of the study (Strauss and Corbin, 2008). Although it is purposefully biased, combining theoretical sampling with homogeneous and snow bowling sampling will facilitate obtaining information that can further fine tune and improve the findings of this study.

3.7.2 Data Collection Methods for Eliciting Information Requirements

Scenario Development

As defined by the Oxford Dictionary (2008), a scenario is a postulated sequence or development of events. Scenarios are commonly used in fire training technique, and efforts are always made to ensure to make them as realistic as possible. However, what is more important in this type of study is to present a challenging scenario (Militello et al., 1997). Therefore, several challenging situations, which are familiar to the participant SMEs, will be selected to form paper based scenarios.

Several high-risk fire incident scenarios will be formed as stories describing each incident with the options of introducing quick variants to the original situation. Since high-risk fire sites often maintain their own operational risk assessment documents including photographs, maps and procedures, it is recommended to include such documentations along with the developed story.

Interviewing

Most of the qualitative literature describes three basic approaches to collect qualitative data through in-depth interviews. For example, Patton (2002) defines them as informal conversational, general interview guide approach and standardized open-ended interview. Silverman (2006) adopted the work of Noaks and Wincup (2004) to illustrate three similar methods namely: Open-ended, Semi-structured and Structured interviews. Furthermore, Leech (2002) introduced similar classification of unstructured, semi-structured and structured interviewing. These approaches are more or less similar to each other although they use different terminology. The three approaches involve different types of preparation,

conceptualization and instrumentation (Patton, 2002). Each approach has its own strengths and weaknesses depending on the context of their application (Patton, 2002).

When the interviews require focus and control but in parallel aim to elicit in-depth insider's perspective, it is recommended to use the middle ground technique of semi-structured interviews (Patton, 2002; Silverman, 2006; Leech, 2002). These include an interview guide supported by various forms of interview probes consisting of topics or subject areas about which the interviewer is free to explore (Patton, 2002). The interviewer can decide in advance what areas to be covered, but he/she must be open and receptive to unexpected information from the interviewee (Hancock, 2002; Hancock et al., 2007). This can be particularly important in a situation where limited time is available for interviewing and the interviewer wants to be sure that the "key issues" are covered (Hancock, 2002; Hancock et al., 2007). Therefore, appropriate use of semi-structured interviewing is capable of increasing the effective use of the contact time with participants, which is often rare and precious. Based on the above considerations, this study proposes to use the semi-structured interviewing technique as its core information gathering tool.

For each interview phase of this study, an interview guide is developed consisting of several fire scenario probes. These scenario probes are designed on the basis that the interview participants are familiar with the fire incidents selected for the scenario building. As its primary planned interview probes (McCracken, 1988), interview guide for the task capturing interviews consists of suitably designed grand tour question/s (Spradley, 1979), which are specific and open-ended. When necessary, a few floating prompts and variations are introduced in addition to the primary scenarios to facilitate a continuous and meaningful discussion (McCracken, 1988). During the goal capturing interviews, open-ended questions specifically based on the previously captured tasks are used in addition to the use of primary scenario probes. In the final phase of the interviews, open-ended questions developed with the use of goals and sub goals will act as the predefined grand tour questions (Spradley, 1979). Such open-ended questions, probed together with the support of the scenarios motivate the interviewees to describe their requirements of decision-making followed by the corresponding information requirements. To obtain more specific and elaborative information and decision requirements relevant to particular sub goal/s, its higher-level goal serves as the planned secondary discussions prompt (McCracken, 1988).

Although an interview guide is likely to ensure focus and structuredness of an interview, continuous maintenance of openness in the questions allows the researcher to cover a higher number of discussion points. It is crucial to maintain such balance during the interviews since it allows the participants to express their thoughts related to their information requirements, and avoid deviating from the research topic. This also enables the interviewer to maximize the effectiveness of the interview time and to cover the complete range of discussion topics leading to information rich descriptions. All the sessions are voice recorded and later converted in to a written transcript.

Observations and Document Reference

In the context of case study approach direct observations provide the opportunity of absorbing and noting details, actions, or subtleties of the field environment (Webb et al., 1966). Observations enable the researcher to see things that may routinely escape the conscious awareness of the researcher and learn about things that SMEs may be unwilling or unable to talk in an interview (Patton, 2002). The level of achieving such advantages depends solely on the extent of participation (Patton, 2002). The choice of the extent of participation should be consciously made by the researcher depending on the assessment of the merits and demerits in each particular case (Walsham, 1995). Although it is impossible to have an opportunity to observe a large-scale real fire, this study intends to seek as many as opportunities possible to conduct field observations in an environment, which closely resembles an actual fire. Also, efforts are exerted to move more in to the complete immersion side of the continuum of the extent of participation rather than making observations merely as an observer..

Making purposeful field notes are considered as paramount (Patton, 2002; Hammersley and Atkinson, 1995; Myers, 1999). A suitable voice recorder is used judiciously so as not to become intrusive and inhibit social processes (Patton, 2002). Digital video and still image cameras are also used in parallel to making field notes (Prosser and Schwartz, 1998; Pink, 2007) whenever the context is favourable and the equipment does not obstruct the activities (Patton, 2002). Immediately after each observation session, field notes are transferred on to a separate document. Each field note embeds the video clips, photographs or/and voice clips, which illustrate the event or events enhancing the descriptions captured under that particular field note. The photographs, videos and voice clips are numbered to make a

catalogue so that all the information related to the observation can be accessed easily and quickly on later occasions.

Appropriate study of documentation is also one of the primary data collection methods (Benbasat et al, 1987; Yin, 2002). Study of fire and rescue related documentation is likely to provide useful information, especially during the initial stages of the information gathering efforts. Also during the analysis, appropriate document referencing and the field observations are used as additional sources of triangulation of various interview findings.

3.7.3 Data Validation Methods for the Findings of GDIA

Validation of both goal structures and the GDI diagrams is proposed to be informal and flexible. Selection of SMEs for the validation sessions is dominated by the “Homogeneous Sampling” (Patton, 2002), “Snowballing” (Patton, 2002) and “Theoretical Sampling” (Strauss and Corbin, 2008). Therefore, there is a possibility of engaging SMEs who are very senior or experts as participants. This category of participants may not have sufficient time to go through all the planned interviewing steps. Yet to improve the validity of the findings their participation is vital. On some occasions, due to time constrain, several participants may get together in providing feedback. Therefore, participation of multiple SMEs for a session is a possibility. It is not feasible to discuss all the findings during a single discussion, so items to be discussed are selected randomly during both goal and GDI validation sessions. The findings are introduced in a pre-discussion session as a means of saving time for the discussion on item validation. This allows participants to become familiar with the findings. However, this is not feasible for all the occasions as accessibility to the SMEs can be limited. Therefore, validation becomes a less formal discussion. Brainstorming (Maguire and Bevan, 2002) is selected as the technique to conduct the validation sessions. The results of a brainstorming session are a set of good ideas and a general feel for the solution area to meet user needs (Maguire, 2001a). Feedback during the validation sessions is collected in the form of written statements as SMEs are able to add, delete or edit the elements of the diagrams. In addition, all the brainstorming sessions are voice recorded and later converted in to a written transcript.

3.7.4 Data Analysis Methods for Eliciting Information Requirements

Analyzing data is the most difficult and the least codified part of the research process (Eisenhardt, 1989). Qualitative analysis intends to transform the data into findings (Patton,

2002). According to Patton (2002), there is an abundance of guidelines but applying guidelines requires judgment and creativity. Therefore, prior to selecting an appropriate guideline, effort is made to understand the applicability of some of the prominent qualitative data analysis methods. Each method seeks to condense the bulk of the data into analyzable units by creating categories with and from the data itself (Coffey and Atkinson, 1996). Therefore, these techniques are often described as a variation of content analysis or a constituent of content analysis (Berg, 2006). The characteristic of data comparison is common to all the tools (Patton, 2002) and emerges from the principles of “Constant Comparison.” “Constant Comparison” is a technique later developed in to a theory based analysis tool called the grounded theory (Patton, 2002). In recent times, grounded theory has become popular in the domain of IS as a data analysis technique for other forms of qualitative research methodologies. Recent evidence (Andrade, 2009; Renken and Moswetsi, 2006; Eisenhardt, 1989) shows that the combination of case studies and grounded theory has been rewarding for IS researchers (Fernandez et al., 2002). Whilst in the traditional case study methodology there is no prescribed formula for interpreting findings and the interpretation of results is free form; the grounded theory sets down a stringent regime of rigorous steps for the interpretation and presentation of findings (Fernandez et al., 2002).

Boeije (2002) produced a purposeful approach to the simple use of “Constant Comparison” and introduced simple but clear step by step approach to the application of the method by meaningful integration of previous work by Dey (1999). This study proposes to use the Boeije’s interpretation of “Constant Comparison” method. Importantly data analysis of this study is made up of two activities namely “fragmenting” and “connecting” (Dey, 1993). Both strands are necessary and keep each other in equilibrium (Boeije, 2002). During the first activity, the conversation parts of each interview followed by the field notes and document referencing are separated out. This involves close listening, reading and line-by-line analysis. The process of fragmenting lifts the coded pieces out of the context of the data gathering (Example: interviewing) as a whole (Boeije, 2002). The second activity of the analysis process consists of interpreting the parts as a whole and connecting the pieces together.

This study intends to obtain participation of SMEs having different levels of experience and from various fire stations within and beyond the boundaries of one particular FRS. It will

also involve participation of SMEs who are designated outside the particular job role under investigation but capable of expressing useful views related to that particular job category. For example, Command Support teams may provide useful feedback on the requirements of Incident Commanders. Furthermore, specialists who are complete outsiders to the FRS may also be capable of providing some useful information. Apart from having interview data, data may also come from other sources. This leads to following comparison steps during the analysis:

- Comparison within a single interview.
- Comparison between interviews within the same group or other forms of data sources.
- Comparison of interviews from different groups within or outside a particular fire service.

Comparison of data of this study starts from the form of categorization namely “Open Coding” (Glaser and Strauss, 1967). These categories are developed inductively during the analysis of the qualitative data. This is followed by the concept of “Axial Coding” (Boeije, 2002). This allows the researcher to compare fragments from different interviews that the researcher has interpreted as being in the same category or sub category (Boeije, 2002). Such realizations lead to combine the fragments to formulate a new concept. Finally, findings of the qualitative analysis are triangulated by comparing the qualitative data of two or more groups of participants. Comparisons further allow obtaining additional information related to a particular category and therefore, enhance the interpretation of the concepts. This allows validating the concepts being developed by either confirming or casting doubt on it.

GDIA requires several broad categories of the data, namely: tasks, goals, decisions and information. By dividing the interviewing in to several distinctive phases, this study enables the use of the themes identified in one phase to guide the data categorization of the following phase. For example, at the end of the analysis of goal related interviews, identified concepts of goal structures will form the basis of the categorization of the phase of information capturing.

3.7.5 Triangulation, Validation and Generalisability of the Findings

Building checks and balances into a design through multiple data collection strategies is called triangulation (Patton, 2002). Denzin (1989) has identified four basic types of triangulation:

- Data Triangulation – use of a variety of data sources
- Investigator triangulation – use of different evaluators
- Theory triangulation – use of multiple perspectives of perspectives for interpretation
- Methodological triangulation – use of multiple methods to a single problem.

Although ideal, triangulation is an expensive practice. Therefore, only the possibilities of using Data triangulation and Methodological triangulation are investigated. This study proposes to use data triangulation within a single case study by interviewing people in different status positions or with a different point of view. For example, Experienced and Novice, Fulltime and Retained firefighters can be used. It is also proposed to incorporate methodological triangulation with the use of different types of data collection methods wherever and whenever feasible. Apart from semi-structured interviews, data collection via observations and document referencing is proposed to improve the methodological triangulation of this study. However, the use of triangulation methods are not considered a way of obtaining a ‘true’ reading, but are best understood as a strategy that adds rigor, breadth, complexity, richness and depth to the inquiry (Denzin and Lincoln, 2000).

Corresponding to the validity of qualitative research, there is a variety of definitions (Golafshani, 2003). Literature tends to use the terms triangulation, validation and generalization almost as synonyms. Having studied various interpretations of Davies and Dodd (2002), Lincoln and Guba (1985), Seale (1999), Stenbacka (2001), Silverman (2006), Patton (2002) and Maxwell (1992), Golafshani (2003) concluded that triangulation is a strategy of reaching validity for qualitative inquiry. Similarly, Mathison (1988) argued triangulation as a strategy for improving the validity of qualitative research. Therefore, as argued by Golafshani (2003) and Mathison (1988) triangulation can be defined as a validity procedure (Creswell and Miller, 2000) for qualitative research. Among a variety of validity categories relevant for the qualitative inquiry, this study recognizes the importance of maintaining following validity classes identified according to the classification of Maxwell (1992):

- Descriptive Validity
- Interpretive Validity

- Generalisability

Descriptive validity is crucial during this research as it checks the factual validity (Maxwell, 1992); that is whether the evaluators or investigators make up or distort the things they saw or heard. Maxwell (1992) defines interpretive validity as a concept exclusive for interpretive inquiry. Having considered its interpretive nature, interpretive validity is considered as equally important for this study. Compared to valid description of the physical objects, events and behaviours in the settings of the study, interpretive validity improves the meaning of such elements from the perspective of the participant.

Generalisability refers to the extent to which one can extend the account of a particular situation or population to other persons times or settings than those directly studied (Maxwell, 1992). Synthesizing the arguments of Golafshani (2003) and Stenbacka (2001), this study defines generalisability as one of the extensions of validity. It is important to carry out discussions with the SMEs who are non participants during the GDIA interviews but representing the same FRS since it improves the internal generalization of this study. In addition, extending discussions to FRSs different to the main site of data collection to evaluate the findings of the GDIA process improves the external generalisability.

3.8 Presentation of User Requirements

Any computer based system that supports its end-users always presents relevant information and communicates via a suitable human computer interface (Shneiderman et al., 2009). Most think the user interface as something that comes after the design of the physical system (Endsley et al., 2003b). This approach is considered to be poor since overall system effectiveness is largely determined by the physical nature of the displays and controls (Endsley et al., 2003b). Furthermore, if changes required to the design of a system are visualized only at the last phase of a system development when the user interface is developed this can become quite expensive and difficult to modify (Endsley et al., 2003b; Maguire, 2001a). Therefore, the user interface needs to be specified very early in the design phase and can potentially be the key driver of the physical development of the system.

According to Maguire (2001a) and Endsley et al. (2003b), what is more important during an evolutionary development of an information system is to create an appropriate prototypes consisting of human computer interfaces early. This allows valuable design input from

users and developers. To achieve the second objective of this study it is decided to select a suitable prototyping technique to elicit the end-user's expectations and feedback on how the human computer interfaces should present the information needs. Selection of a prototyping technique depends on the expected output and the constraints such as available resources, training needs and time requirements (Shneiderman and Plaisant, 2004).

3.8.1 Selection of Prototyping Technique

There are various forms and types of prototyping techniques, which can be positioned in a continuum from low fidelity to high fidelity (Hackos and Redish, 1998; Engelberg and Seffah, 2002; Petrie, 2006). Maguire (2001a) has developed a classification comparing the capabilities and application of these prototyping techniques. This classification recommends types of prototyping techniques to be selected at a particular stage in the system design process. According to this classification, a software mock-up capable of simulating the functionality of the actual system on a computer interface is identified as an appropriate technique for the in-depth testing of top-level design of a system. Software mock-ups are throw-away type prototypes of the system produced to help discover requirements problems and then discarded (Sommerville, 2006). The system is then developed using some other development process (Sommerville, 2006). As explained earlier, the aim of this study is only to validate information needs and to understand the deployment and presentation of information needs of firefighters. Thus, the type of prototypes to be built-in this particular study could be defined as throw-way mock-ups primarily consists of Graphical User Interface (GUI). It is decided to use the support of some form of software mock-ups to reach the second objective of this study.

3.8.2 Selection of Mock-up Development Tool

Currently, in the software market, there is a large number of third generation and fourth generation software tools available for the development of mock-up GUI displays. Among them some tools (Appendix 3.1), which are popular among rapid application developers (Endsley et al., 2003b; Hackos and Redish, 1998), are considered the most appropriate for this study. As a guideline, the key findings of the survey carried out by GUUUI (2008) on lead to the following criteria for this particular study.

- The selected tool must be user friendly and should require minimum training.
- Application should require less hardware resources during installation.
- Tool should be affordable to purchase and maintain.

- Duration of the development time should be quick.
- Tool is not expected to generate any software coding. This study is not intended to develop the actual system.
- Tool should be able to develop higher-level of user interactivity.
- Tool must provide facilities for quick and easy revision and layout. So that even in a middle of a demonstration session, changes required by the end-users can be quickly accommodated to get further feedback.

The software prototyping tool GUI Design Studio and Adobe Flash are selected as the most appropriate for this study. GUI Design Studio (Version 2) is a graphical user interface design tool for Microsoft Windows environment. It is capable of creating demonstration mock-ups rapidly without any coding or scripting. It is an ideal tool for creating presentations to end-users and stakeholders to verify requirements and designs to explore alternatives and to evaluate different usage of scenarios. This particular tool does not require much training or practice. Although it is capable of developing mock-up user interfaces embedded with static content rapidly, this tool is weak in embedding dynamic content (Sommerville, 2006) onto the interfaces. To overcome such limitations Adobe Flash; an animation software tool is selected as the secondary tool. This is used to present any interface element, which is highly dynamic in nature.

3.8.3 Development of Software Mock-ups

Using the selected prototyping tools, software mock-ups consisting of appropriate human computer interfaces for the four selected firefighter job roles will be developed. This should be considered as the first step of an evolutionary development program of an fully-fledged IS supporting firefighters during their response. Whilst building the software mock-ups, the previously elicited information requirements will be mapped to form human computer interfaces of each job role. As stated in the software prototype classification of Maguire (2001a), these software mock-ups may not simulate the functionality of a fully operational prototype IS supporting firefighters. Mock-ups will be designed to illustrate various simulations of functionality capable of providing satisfactory degree of look and feel expected by the end-users to demonstrate the capabilities the system should provide to the users. To achieve such simulation capabilities, the expected context of use of the actual system represented by the mock-ups will be considered (Maguire and Bevan, 2002; Bevan and Macleod, 1994). Maguire (2001b) identified four major categories of contextual factors, User groups, Tasks, Technical Environment, Physical and Organizational

Environment. Under each category, Maguire (2001b) defines key “Context of Use Factors” crucial during the development of any user centered system. Similarly, Endsley et al. (2003b) have proposed a user interface design process. This process stresses the importance of considering the context of use in addition to the actual end-user information requirements. Endsley et al. (2003b) define environmental conditions and user characteristics as two important factors to be considered during the development of user interfaces capable of presenting end-user SA requirements. Endsley et al. (2003b) stress technology analysis as the second most important factor after the requirements gathering in the process of information systems design. A broader approach to systems design has the advantage of designing a product usable to real users who carry out actual tasks in a real technical, physical and organizational environment (Bevan and Macleod, 1994). Thus, it is important to consider the design implications that can be caused by various contextual factors unique to the fire emergency context. This is achieved via face to face interviews with SMEs, observations of firefighter training simulations and visits to fire stations and control rooms. Understanding the relevant criteria is further strengthened by referring to the fire and rescue policy and procedure documentation.

According to Endsley et al. (2003b), the way in which information is presented to the operator through the interfaces greatly influences their SA by determining how much information can be acquired in the limited time available, how accurately it can be acquired and the degree to which that information is compatible with the operator’s SA needs. Therefore, it is essential to incorporate appropriate human computer interface design principles and guidelines to design a system that aims to improve the end-user’s SA (Endsley et al., 2003b). The selected design guidelines and principles should be able to meet the physical, perceptual and cognitive attributes expected in the human computer interfaces (Endsley et al., 2003b).

3.8.4 Demonstration of Mock-ups and End-user Evaluations

The mock-up interfaces will be demonstrated to the SMEs located across the FRS brigades of the counties selected for the first objective of the study. Efforts will also be made to extend the demonstrations to the important fire emergency related organizations such as UK Fire Protection Association and Fire Service College of UK. The feedback is later used to propose useful modifications to the initial design of the proposed interfaces.

Essentially there are three levels of formality when performing evaluation of early systems designs (Maguire, 2001a): participative (least formal), assisted (intermediate) and controlled evaluation (most formal). Less formal methods are the most cost and resource effective to understand, identify and fix usability problems early in the design process (Maguire, 2001a). Furthermore, according to Maguire (2001a), a participatory approach is more appropriate during the early stage of the system's design. These types of evaluation sessions include questions asking the user for their impressions on a set of screen designs: *what they think different elements may do?* and *what they expect the result of their next action to be?* The user may also be asked to suggest how individual elements could be improved (Maguire, 2001a).

“Evaluation Workshop” (Fitter et al., 1991) is one of the variants of participatory evaluation (Maguire, 2001a). Ideally users and developers meet together and the user representatives use the system to accomplish set tasks while designers observe. The designers later explore the issues identified through a facilitated discussion. Several trials can be run to focus on different features or versions of the system.

“Evaluation Walkthrough” (Nielsen, 1993) is a similar process where a member of the design team goes through a systems design step-by-step getting reactions from participants. A human factors specialist should facilitate the walkthrough while one or more users will comment as the walkthrough proceeds. A list of problems is drawn up by consensus and corresponding severity ratings are defined as they arise. When the design elements are examined, the problem list and severity levels should be reviewed and changes should be proposed (Maulsby et al., 1993; Nielsen, 1993).

Both evaluation workshops and evaluation walkthrough are similar in their application, except workshops provide more opportunity to use the prototype by the end-users themselves during the evaluation session. On the other hand, walkthrough session is mainly controlled by a human factor specialist. Both evaluation walkthrough and workshops can provide a powerful assessment of a design concept (Stanton et al., 2005). Both these methods are questioned for their reliability despite their capability of providing rich feedback. The natural tendency is that end-users react positively when they see some form of prototype in operation (Magurie, 2001a). In addition, output of both these methods is usually in the form of opinions rather than objective data. Although it is impossible to

quantify or measure the feedback, evaluation discussions should be formulated in such a way that it decreases most of the other shortcomings.

Before using workshops and walkthrough, it is important to consider the constraints unique to this particular study.

- Participants could be either an individual fire and rescue officer or group of officers.
- Evaluation steps must be flexible enough to accommodate any number of participants since accessibility is difficult and limited.
- Availability of human resources to conduct the evaluation session is limited to only a single prototype designer (In this study the researcher).

3.8.5 Evaluation Method of the Software Mock-ups

Without stipulating what type of methods should be used, ISO 13407 (ISO, 1999) standard is developed as a framework for applying user centered design, which can be applied to workshop and walkthrough evaluations. With the objective of promoting the ISO 13407 standard, RESPECT Consortium has produced a comprehensive list of user based specification on practices adopted by the industry. This specification is likely to benefit the design of Human Computer Interaction (HCI). Thus, it is decided to derive the steps of the evaluation method for the software mock-ups based on the handbook published by the RESPECT consortium (Maguire, 1998 as follows:

1. Select appropriate users to take part in each walkthrough.
2. Decide clearly what issues or task scenarios should be covered in each walkthrough..
3. Ensure availability of a use high performance recording device to voice record throughout the evaluation session.
4. Give an introduction to the participants at the beginning of each evaluation session, explaining the aims of the session and general overview of the study. Describe beforehand the range of tasks to be covered.
5. First conduct a walkthrough session by the designer. Approximate duration is 1.5hrs.
6. If there is more than one participant, arrangements should be made to pre-load the GUI simulator to several computers.
7. Walkthrough session is followed by a workshop session where participants are allowed to try out the pre-loaded mock-ups themselves. Designer acts as the facilitator. Approximate duration is 1hrs.

8. After the short workshop, a question and answer session is conducted to clarify issues related to:
 - the end-user perception on overall ability of the system to support their decision-making, performance drawbacks and means of overcoming them. During this session, all participants are encouraged to express their opinions in detail.
 - the possible SA Failures during the design of an information system.
 - identify the end-user environment and technology suitable to deploy the actual system and obtain participant preferences.
9. Voice files of each evaluation session are transcribed.
10. The issues raised and comments made are analysed similar to the analysis method described in the Section 3.7.4.

The evaluation sessions will be extended beyond the participation of active firefighters by including independent experts working in the fire and rescue related organizations. Three purposeful sampling techniques, “Homogeneous Sampling” (Patton, 2002), “Snowball Sampling” (Patton, 2002) and “Theoretical Sampling” (Strauss and Corbin, 2008) are combined to support the selection of an appropriate sample for the mock-up evaluation. Most of the participative evaluation methods recommend the use of several facilitators in the form of demonstrators and note takers, but this study is limited to a single facilitator. Thus, for better control it is decided to limit the number of participants for an evaluation session to a maximum of five.

3.9 Information Systems Architecture for Fire ER

This study also proposes an Information Systems Architecture (ISA) with the aim of reaching its third objective. Ideally this architecture should provide further guidance for both the clients and the system architects and designers to build an actual system based on the findings of the first two objectives this study. Therefore, prescription of this conceptual ISA is driven by the validated information requirements and the human computer interaction needs of the end-users.

3.9.1 Approach to the Proposal of Conceptual ISA

It is important to clearly define the position of the information systems architecture to be proposed. The analogy between traditional building architecture and Information Technology based systems architecture is central to ISA. This has led Zachman (1987) to describe six types of architectural perceptions or views : *planner’s view, owner’s view*

drawn by the architect, designer's view drawn by the architect, contractor's view drawn by the contractor, subcontractor's view drawn by the sub-contractor and finally the enterprise view, which is the building itself. These perspectives are complemented with *types of description* (Zachman, 1987), i.e. the kind of questions that can be asked about a given view. Zachman (1987) prescribes three types of description: *data*, *function* and *network*, which answers the questions, *what*, *how* and *where*. These two orthogonal dimensions form a six by three ISA matrix in which the rows represent the six perspectives and the columns represent the three types of description. Later, Sowa and Zachman (1992) added three more types of descriptions: *people*, *time* and *motivation*. They correspond to the questions, *who*, *when* and *why*. The Figure 3.5 show this extended ISA framework.

| | DATA <i>What</i> | FUNCTION <i>How</i> | NETWORK <i>Where</i> | PEOPLE <i>Who</i> | TIME <i>When</i> | MOTIVATION <i>Why</i> |
|------------------------------------------------------------------------|------------------------------------------|----------------------------|----------------------------------|---------------------------------|----------------------|------------------------------------|
| Objective/Scope (contextual) <i>Role: Planner</i> | List of things important in the business | List of Business Processes | List of Business Locations | List of important Organizations | List of Events | List of Business Goal & Strategies |
| Enterprise Model (conceptual) <i>Role: Owner</i> | Conceptual Data/Object Model | Business Process Model | Business Logistics System | Work Flow Model | Master Schedule | Business Plan |
| System Model (logical) <i>Role: Designer</i> | Logical Data Model | System Architecture Model | Distributed Systems Architecture | Human Interface Architecture | Processing Structure | Business Rule Model |
| Technology Model (physical) <i>Role: Builder</i> | Physical Data/Class Model | Technology Design Model | Technology Architecture | Presentation Architecture | Control Structure | Rule Design |
| Detailed Representation (out of context) <i>Role: Programmer</i> | Data Definition | Program | Network Architecture | Security Architecture | Timing Definition | Rule Speculation |
| Functioning Enterprise <i>Role: User</i> | Usable Data | Working Function | Usable Network | Functioning Organization | Implemented Schedule | Working Strategy |

Figure 3.4: Framework of Information Systems Architecture

According to Zachman (1987), the “Planners View” results from the initial conversations between the architect and prospective owner. The architect can depict what the owner has in mind in the form of a series of bubbles; each bubble represents in gross terms the size, shape, spatial, relationships and basic intent of the final structure. Hence this view is called a “Bubble Chart” Zachman (1987). The “Owner's View” (Enterprise or Business Model) comprises architect's drawings that depict the final building from the perspective of the owner who will have to live with it in the daily routines of business. These drawings correspond to the enterprise model or a conceptual architecture of an information system, which constitute the designs of the business. They show the business entities, processes and how they relate. The “Designer's View” (Information Systems Model) comprise architect's plans that depict the translation of the architect's drawings into detail requirements from the

designer's perspective. They correspond to the system model of an information system designed by a systems analyst who must determine the data elements, logical process flows, and functions that represent business entities and processes.

However, it is evident that “Planner’s View” is not detailed enough to have a comprehensive understanding of the components of an IS capable of supporting firefighters and functionality of those components. This study intends to specify an ISA depicting the “Owner’s View” of the Zachman’s (1987) ISA framework. This should provide a comprehensive conceptual architecture understood by firefighters, FRS and the architects and designers of fire emergency ISs. Hence, a conceptual ISA exclusively capable of supporting firefighter decision-making in a response phase of a fire emergency is proposed after careful study of the following:

- End-user information requirements.
- End-user information presentation and sharing requirements.
- Capability of proven software and hardware technologies to look after the above identified end-user requirements.
- New software and hardware technology needs to overcome the limitations of presently available technologies.

This architecture should essentially prescribe conceptual level description related to *data*, *function* and *network* of an IS supporting fire emergency response work.

3.10 Summary

In this chapter a detailed analysis of an appropriate research philosophy, strategy and methodology, which will guide the way this study is conducted, is presented. This includes substantial literature review and in-depth explanation and discussion in relation to the selection and development of methods and research techniques suitable to reach each objective of the study. The chapter has also introduced and discussed various Meta methods appropriate for sampling, data collection, analysis and validation.

Chapter 4 : Elicitation of Information Requirements and Analysis

4.1 Introduction

The first objective of this study was to elicit the comprehensive information requirements of the firefighters responding to a fire emergency in a high-risk built environment. Thus, the aim of this chapter is to explain the complete process of how these information requirements were elicited in several stages. Since this study is conducted within the context of the UK Fire and Rescue Service (FRS), the chapter begins with introducing operational context of the UK FRS. Subsequently, it explains the selection of important job roles to conduct the study. The chapter also provides background information on the three FRS brigades located in the East Midlands region, specifically selected to carry out the exploratory work of this study. This is followed by a discussion on identifying the appropriate primary and secondary high-risk incident sites and the development of fire incident scenarios. Thereafter, this chapter explains the details of the information requirements elicitation efforts carried out with the use of the CTA tool: Goal Directed Information Analysis (GDIA). This discussion includes the stages of: 1) Task Elicitation, 2) Goal Elicitation and Validation, 3) Elicitation of Decision and Information Requirements and 4) Development and Validation of Goal-Decision-Information (GDI) Diagrams for the firefighter job roles being investigated.

4.2 Fire Emergency Response (ER) Operational Context of UK FRS

Since this study is primarily focused on the context of UK FRS, at the beginning detail explorations were made specifically to understand its operational context. These explorations were based on the reference made into the procedure, policy and service documentations related to the UK FRS. Some early observations of several fire and rescue practices and initial discussions conducted with fire and rescue officials were also helpful to strengthen the contextual understanding.

It was revealed that within the context of UK FRS, response to any fire emergency is managed and coordinated by its Control Room and the Incident Command Structure (Fire Service Manual Volume 2: Incident Command, 2008).

4.2.1 Control Room

The ER to a fire always begins at the Control Room of the respective FRS. In the UK, a centralized system for the receipt of emergency calls operates from the Control Room of most of the counties.

Responsibilities of a Control Room

- Handle all the incoming fire incident calls.(Record them, Identify true request from malicious).
- Identify the correct location of the incident.
- Depending on the pre-identified risk levels,
 - Deployment of rescue teams.
 - Deployment of initial resources.
- Provide initial information to the deployed rescue teams (location and directions).
- Maintenance and Mobilization of all available resources through out, including human resource.
- Coordinate and maintain enough backup resources throughout.
- Maintain continuous coordination with the incident command located at the fire front and provide continuous support with the resources.
- Make strategic decisions regarding allocation of limited resources to a fire front, especially during multiple fire incidents.

Control Room Staff

To carry out such responsibilities Control Rooms usually operate with the support of Supervisory/Managerial role and Radio & Telephone operators (Control room operators).

4.2.2 Incident Ground Command Structure

Apart from the Control Room, the next most important structure for an emergency is its Incident Ground Command Structure, which commonly known as the Incident Command Structure (Bigley and Roberts, 2001). Usually Incident Ground Command Structure operates from a temporary control room located at the emergency front. After identifying the actual location, initial diagnosis of the risk level and deployment of initial resources by the Control Room, total control of managing the incident will be handed over to the Incident Command Structure on-site at the incident.

Responsibilities of the Incident Command Structure

According to the UK FRS policy and procedure (Fire Service Manual Volume 2: Incident Command, 1999; 2008), the main responsibilities of the incident command structure are:

- Identification of Span of Control for each supervisory level during the operation.
- Carry out the sectorisation process.
- Preparation and implementation of the tactical plans (How to attack the fire offensive, defensive, etc.).
- Deployment & Mobilization of resources received from the Control Room.
- Requesting resources according to the situation.
- Coordination among all management levels at the incident location.
- Maintain communication and coordination with the control room throughout an incident.
- Coordination of other auxiliary support services such as police, ambulance, press.
- Continuous monitoring and review of situation assessment.
- Maintain records of all operational activities during a fire.

Typical Job Roles of an Incident Command Structure

During the different phases of an incident progress, the responsibilities of incident command structure will be shared among several important staff roles, which vary depending on the complexity of the incident. During a typical fire emergency, those staff roles can be identified as follows.

Incident Commander (IC): The Incident Commander will normally be the most senior officer present at the incident, according to each brigade's policy determining ranks and responsibilities at incidents. The IC is responsible for the overall management of the incident and focuses on command and control, deployment of resources, tactical planning, coordination of sector operations, Breathing Apparatus (BA) search coordination and the health and safety of crews. An IC continually makes an assessment of the incident and decides the most appropriate *Tactical Mode*. Also, an IC must inform the control room about the *Tactical Mode* in operation at the incident and ensure confirmation is repeated at about 20 min. intervals up until the time that the *stop* message is sent. The IC should also consider and confirm the *Tactical Mode* at the beginning and in all subsequent briefings to crew and sector commanders.

Operations Commander (OC): The role of Operations Commander exists as a means of maintaining workable spans of control when the incident develops in size and complexity.

If, for example, the incident has *four* operational sectors, some support sectors (Example: water, decontamination, salvage, etc.) and there are also demands for the Incident Commander's time from press, specialist support, other services etc., then the Incident Commander's span of control is likely to be at its upper limit. In this example, the operational sectors can be condensed to one line of communication by using an Operations Commander.

Sector Commander (SC): A Sector Commander will be appointed for each sector and takes responsibility for the resources within the sector and management of the sector. The SC will principally focus on command and control, deployment of resources, tactical planning, BA search coordination, and health and safety of crews, in close conjunction with the IC, or OC if one is in place.

Crew Commander (CC): One sector of the operation may be divided into several crews. In this situation, to manage each crew there will be a CC. He will monitor the conditions in the risk area and draw the attention of the SC to significant developments.

Breathing Apparatus Entry Control Officer (BAECO): It is the sole responsibility of the nominated BAECO to supervise a single Entry Control Board (ECB) and monitor the Breathing Apparatus (BA) Wearers who have entered the incident via an Entry Control Point (ECP).

Fire Fighter/Working Crew Member: Crew members are members of the incident command hierarchy who directly involved with the fire fighting. During the response phase, these officers may hold various job responsibilities such as ventilation, search and rescue, salvage, overhaul forcible entry, fire extinguishing, etc. Depending on the incident and the context of the incident, these jobs will be carried out with or without the support of BA.

Command Support (CS): Command Support should be introduced at all incidents to assist the IC in the management of the incident. A team member of CS may take up the following responsibilities:

- Act as first contact point for all attending appliances and officers and to maintain a physical record of resources in attendance at the incident.
- Operate the main-scheme radio link to the brigade control and to log all main-scheme radio communications.
- Assist the IC in liaison with other agencies.
- Direct attending appliances to an operational location or marshalling area as instructed by the IC and to record the status of all resources.

- Maintain a record of the outcome of the risk assessment and any review, as well as any operational decisions or actions taken as a result of it.
- Record sector identifications and officers' duties as the assignments are made.

Safety Officers: Where appropriate Safety Officers are appointed to take responsibility for any Health & Safety reporting issues.

Runners: Runners are helping the job of Command Support.

Management of the Incident Command Structure

Managing the incident command structure is one of the most important activities during an emergency (Fire Service Manual Volume 2: Incident Command, 1999; 2008). Success or failure of an Emergency Response (ER) may depend on introducing different types of supporting roles to an incident command hierarchy. According to the Fire and Rescue policies of UK, the forming and management of an incident hierarchy is always based on two factors, namely *Span of Control* and *Sectorisation*. The ICS uses "roles" instead of ranks to describe responsibilities thus allowing individual FRS brigade to assign the rank to each function according to their own particular circumstances. The standard model allows the structure of the incident to develop in a predictable and manageable way on the arrival of more senior officers. For example, at the beginning of an incident, the IC may hold the rank of Crew Manager (CM) or Watch Manager (WM). If an incident develops into more serious situation, the IC role would normally pass progressively from the first arriving CM or WM to a Station, Group or Area Manager ranked according to the individual FRS brigade's Standard Operating Procedures (SOPs) and orders.

Span of Control : According to the current practice of incident command, the direct lines of communication and areas of involvement of any officer is limited in number to enable the individual to deal effectively with those areas. No individual should be responsible for a number of activities or operations that are difficult or impossible to give sufficient attention to each. Current procedure seeks to ensure that an appropriate *Span of Control* is exercised at all times by the requirement for additional officers to be introduced into the chain of command when the dependency on any one individual's attention becomes excessive.

The *Span of Control* for tactical roles is limited to five lines of direct communications to ensure that commanders do not become over burdened. Nonetheless, the *Span of Control* for logistical role, such as CS Officer, may be wider. In a rapidly developing or complex

incident, the span of control may need to be as small as 2-3 lines. In a stable situation, 6 - 7 lines may be acceptable. During much larger incidents, ICs not only make decisions about tactics, reinforcements, logistical problems, etc., but also build an organization chart mentally at the same time. To avoid mental or physical overload, current procedures provide a clear framework that expands from a one fire engine (pump) attendance to the largest incident that might ever occur and provides the IC with a ready to use organizational framework.

Sectorisation: To manage the *Span of Control* effectively, it is often necessary for the IC to delegate responsibility and devolve authority for some operations. To achieve this, the IC may choose to sectorise the incident. A sector is the area of responsibility of a SC. To assure clear definitions of sector responsibility, sectors must have clearly defined boundaries. There are two main categories of sectors, Operational (Physical Area) and Functional Support (Example: Water Sector, Decontamination Sector, etc.). Apart from formal sectorisation, in bigger incidents, the incident ground is divided into cordons often due to geographical spread (Example: Forests, Moorland, etc) or separation due to spillage and toxic clouds or building collapse. Cordons are employed as an effective method of controlling resources and maintaining safety on the incident ground. The IC must consider the safety of firefighters, the public, members of other emergency services and voluntary agencies attending.

4.2.3 Core Job Roles of Fire Emergency Response Incident Command Hierarchy

Based on the analysis of the incident command structure, its members and the sectorisation policies and procedures, the following roles were identified as the core job roles of an incident command during fire ER (Prasanna et al., 2008; Yang et al., 2009a).

- a) Incident Commander (IC)
- b) Sector Commander (SC)
- c) Breathing Apparatus Entry Control Officer (BAECO)
- d) Breathing Apparatus Wearer (Frontline Search and Rescue Firefighter) (BA Wearer)

Apart from these core roles, other job roles are often introduced to maintain the appropriate span of control and reduce both mental and physical workload of the core job roles. Furthermore, the responsibilities, needs and requirements of other members of the hierarchy

often become a subset of the responsibilities, needs and requirements of these core roles (Fire Service Manual Volume 2: Incident Command, 2008, West Yorkshire Fire and Rescue Service, 2007).

Prasanna et al. (2008) recognized the importance of acquiring information and sharing acquired information among the four core job roles in a coordinated manner during fire ER operations. In addition, remarks similar to the following made by various types of firefighters motivated to consider these core job roles as the most appropriate in achieving the objectives of this study.

One of the Station Managers of the Derbyshire Fire and Rescue :.....*If you want to completely understand the needs of fire fighters during their operations you better talk to people who work as BAs, ECOs, operational SCs and the ICs.....these jobs are the main links of our chain of command.....You simply can't survive without the support of these four jobs during any type of bigger incident.....needs of other jobs are similar to the needs of these four...actually you can say it is a subset....*

One of the Group Managers of the Derbyshire Fire and Rescue:*Of course you have to talk to all the individual job roles in this hierarchy (Pointing to a diagram illustrating comprehensive incident command hierarchy) if you really want to understand our requirementsYeah I know it is impossible.... But if you want to save a lot of time and money you can do almostalmost the same by talking to few key job roles....mmmmm. one is definitely IC....then you must meet BAECO and obviously BAs...and also it will be useful to talk to SCs....by speaking to them will give you more detail operational and functional needs that you may not identify by only talking to ICs.....You can't miss these jobs if you want to understand what we want from any kind of system to support us during large incidents.....*

One of the Business Continuity Officers Derbyshire Fire and Rescue:.... *We can't just consider all these job roles simply as fire fighters each of them have different needs during an incident... So if you want to support us, best scenario is to get all the individual needs.... But in your case it will be a full-time job for several years....the next best option is to identify the job roles that can best cover the needs of the entire command hierarchy... Just by looking at this hierarchy and from my thirty odd years of experience what I can say is that backbone of our this during any category 3 or 4 type of incident is formed by four or five jobs... from command perspective first one is ICs, then OCs and SCs ...then from the*

perspective of BA work the most important jobs are BAECO and BA wearers.....I think you can ignore the work of OC if you can study both IC and SC.....

One of the Senior Officers of Command Support Team Developments Leicestershire Fire and Rescue:.....*If you genuinely want to develop a system supporting us during large incidents my advice for you is to separately understand the needs of the different jobs....you must not miss IC,SC, BA and ECO jobs....even if you only managed to cover these four I can accept you have covered almost 99% of our requirements during operations at the incident site....requirements of other jobs can be part of either one of the above or several of them.*

Based on the preliminary investigations into the UK fire and rescue context, Prasanna et al. (2008) identified the essential Information Systems (ISs) components and information flows necessary to support the core job roles of the ICS during their response (Figure: 4.1)

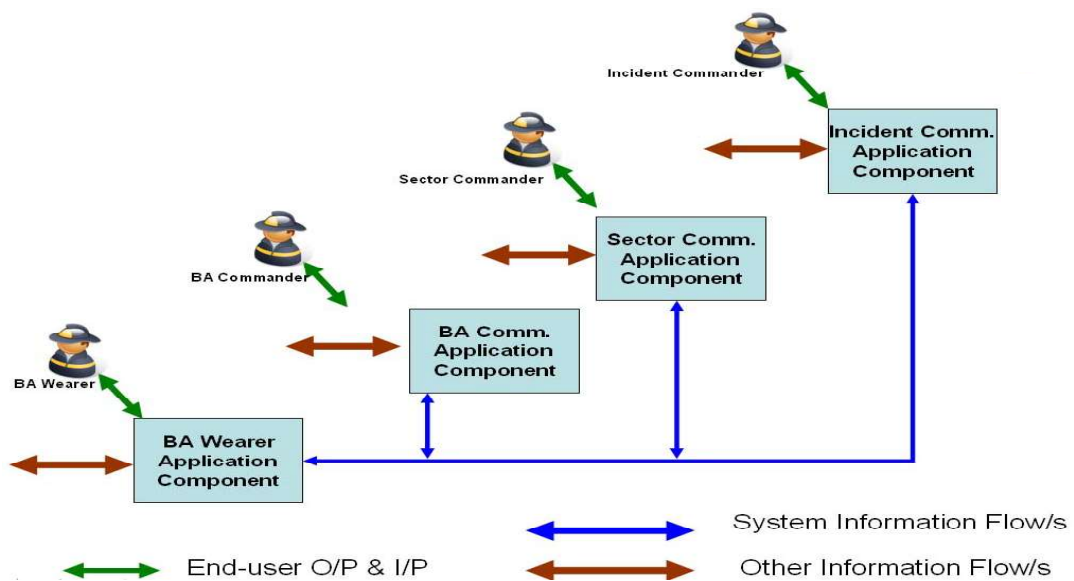


Figure 4.1: Essential Components of a Fire Ground Information System

Consequently, in-depth explorations of this study were focused on the above identified four firefighter job roles (Yang et al., 2009a).

4.3 Selection of FRS Brigades

Having selected the job roles, the next important step was to identify the most suitable FRS brigades to conduct the study. As explained in Chapter 3, selection of FRS brigades to

conduct this study was based on the “Convenient Sampling” strategy (Patton, 2002). The main organization chosen for this study was the Derbyshire Fire and Rescue Service (DFRS). DFRS is the primary end-user collaborator of the “SAFETYNET” project sponsoring this study. This close collaboration enabled the researcher to be assured of access to desired informants at various organizational levels throughout the DFRS. Clearly, this access provided a considerable advantage in conducting the preliminary research at DFRS, rather than at other FRS brigade. However, it is considered desirable to expand the explorations to a wider domain to gain a greater understanding of the key issues within FRS from a variety of different perspectives. This approach allows the researcher to triangulate the results from different sources and thereby ensure greater validity. Thereby, it was expected to expand the study explorations into two other FRS brigades namely Leicestershire Fire and Rescue Service (LFRS) and Nottinghamshire Fire and Rescue Service (NFRS). These two FRS brigades are located adjacent to the operational boundary of the DFRS. Therefore, having a close partnership with DFRS was expected to provide a better access to these two brigades compared to other FRS brigades in the country.

Although the selection of the above cases were primarily based on the strategy of “Convenient Sampling” for better access, the three FRS brigades chosen for the exploratory research had several other significant advantages.

- These three FRS brigades are located in the east midlands region, which is one of the first regions to “go-live” with most of the new Information System (IS) and Information Technology (IT) initiatives under the three main governmental initiatives “New Dimension,” “Firelink” and “FiReControl.” Therefore, these three counties are at the forefront of many of the advancements and changes expected at the national level (East Midlands Fire and Rescue Control Centre Ltd., 2010).
- In these three FRS brigades, motivation to use IS and IT for work practices are much higher compared to most of the other brigades of the country.
- These three counties are geographically much closer compared to other counties in the region and contain more homogeneous built environment profile.
- These three FRS brigades work with a wide range of work practices and technologies ranging from oldest to the newest.
- Geographical location of these counties provided the researcher a much quicker and convenient access to most of its offices, fire stations, training centres and high-risk fire sites.

Having recognized the primary and secondary cases to conduct the study, further efforts were made to understand the specific operational context of the DFRS and subsequently the contexts of the LFRS and the NFRS.

4.3.1 Derbyshire Fire and Rescue Service

Derbyshire is situated within the heart of England and is a county of diversity and contrast, between attractive rural countryside and busy conurbations. Latest figures show that Derbyshire's population is 956,560, which is distributed over some 1,000 square miles. However, nearly three quarters of the population is concentrated in the eastern part of the county, occupying only a quarter of the total land area. Derbyshire has 15 towns with a population of over 10,000, most of which are in the eastern area, including the City of Derby (230,500) and Chesterfield (101,100).

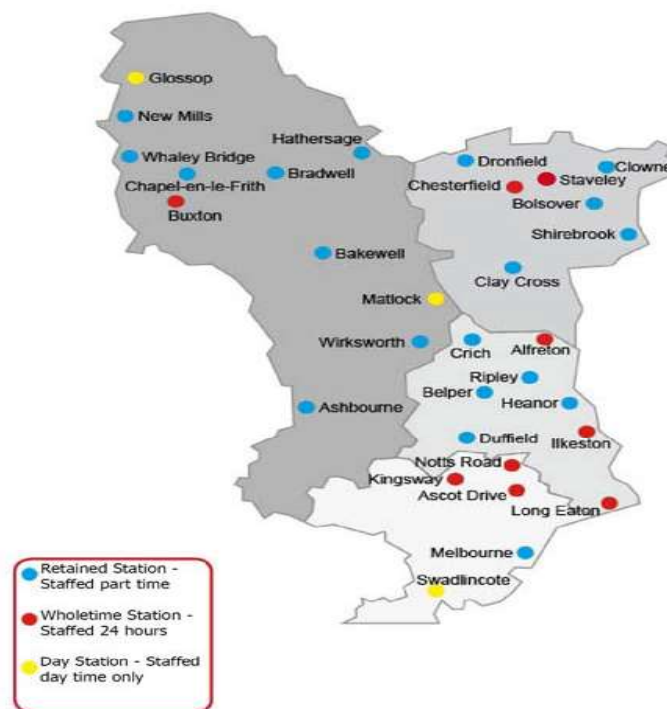


Figure 4.2: Distribution of Fire Stations of Derbyshire Fire & Rescue Service

Fire cover for the county is provided by the Derbyshire Fire and Rescue Service (DFRS), which is governed by the Derbyshire Fire Authority. This Authority consists of 20 councillors, 15 from Derbyshire County Council and five from Derby City Council. The Fire Authority is a separate entity and is responsible for setting the level of revenue funding and the costs incurred in running a “frontline service.” It operates within a legal framework, which is set by Central Government. DFRS has 9 wholetime, 3 day-staffed and 19 retained

fire stations (Figure. 4.2). The wholetime stations are staffed using shift systems, 24 hours a day, 365 days a year from a complement of 456 uniformed personnel, including headquarters and other offices. The retained stations are staffed on a part-time basis from people in the local community who work or live near to their fire station and are able to respond quickly to a notified emergency. They currently number 351. The 33 uniformed control room personnel handle all the emergency calls and mobilize the appropriate response. Public safety is paramount for Derbyshire, and this is reflected in the fleet of constantly updated, modern, firefighting appliances. There are currently 44 fire appliances covering the county along with 13 other “special appliances” such as Aerial Ladder Platforms (capable of rescue from heights of up to 32m), emergency tenders (primarily for road traffic accidents) and a special environmental unit.

High-fire Risk Sites in Derbyshire

After having considered the outcome of the face-to-face discussions with some of the high-ranking officers of the county and based on the information published in the operational risk review documents, the following sites were identified as the highest fire risk sites of the county.

- Westfield Shopping Centre
- Derby Royal Infirmary & Nurses Quarters
- Chemring Defense
- Rolls Royce Marine & Rolls Royce Nuclear Osmaston Road
- Chatsworth House
- Derby Toyota
- Keune and Nagel
- Severn Trent Water Treatment
- Derby University Tower Building
- Bath Street Community Flats

Identification of these sites in the brigade area was determined by an evaluation based on the criteria issued by the UK Home Office.

4.3.2 Leicestershire Fire and Rescue Service

The services of the Leicestershire Fire and Rescue Service (LFRS) are delivered from 20 fire and rescue stations (Figure 4.3), supported by its headquarters, a dedicated training and

development centre, stores and workshops. In total, it employs about 400 full-time and 216 part time firefighters. Furthermore, 89 managers provide logistical and operational support including training, fire protection, operational risk management and contingency planning.



Figure 4.3: Distribution of Fire Stations of Leicestershire Fire & Rescue Service

In addition to the operational personnel, LFRS employ about 130 support staff who carry out key functions in occupational health & safety, finance, human resources, administrative support, democratic services, fleet management, property maintenance and information technology. The service's command and control suite deals with about 27,000 calls each year resulting in an average of 15,000 actual emergency incidents each year.

4.3.3 Nottinghamshire Fire and Rescue Service

In the border of both Leicestershire and Derbyshire, Nottinghamshire Fire & Rescue Service (NFRS) covers an area of 216,000 hectares (834 square miles) with a population of over 1 million. NFRS has a total of 25 fire stations, 12 wholetime and 13 retained. Calls are received at the control room, equipped with a clever fire tender dispatching suite, which is capable of tracking the real-time location of fire engines. The control staff answer each call for help immediately, offer advice to the caller and ensure that the appropriate resources are mobilised to the incident (these include Fires, Road Traffic Accidents, Special Service Calls). NFRS has a solid commitment to have the necessary resources dispatched to any emergency within 60 seconds.

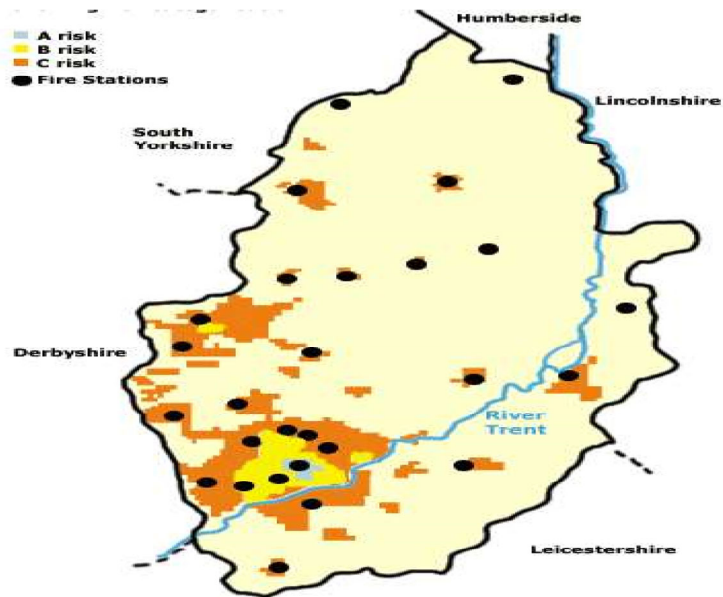


Figure 4.4: Risk Distribution within the County of Nottinghamshire

As with both Leicestershire and Derbyshire, fire calls are currently determined by the Home Office Standards of Fire Cover. Areas of the county are evaluated similar to the standard risk formula adopted by other counties for the categorization of risk (Figure 4.4). When converted into risk categories, they range from “A” risk, which is found in Nottingham City Centre, to “D” risk, which is generally found in rural areas and smaller villages, for example, Misterton in the north and Cropwell Bishop in the south.

4.4 Site Selection and Scenario Building

After initial familiarization of the operational context of the UK FRS and the context of the three specific FRS brigades selected for this study, efforts were further made to select the most appropriate high-risk incident sites. As explained earlier, DFRS was selected as the primary source of information gathering of this study. DFRS not only agreed to provide access to their own resources but also extended their support in getting secondary access to the high-risk incident sites and related information. Therefore, incident sites within the boundary of DFRS were identified as the most suitable for the exploration purposes of this study. At the beginning, several field visits were arranged as a means of getting a better understanding of high-risk fire sites in the county. These include visits to the sites at:

- The University of Derby
- The Westfield Centre
- Derbyshire Royal Infirmary Nurses Quarters

Apart from field visits, DFRS granted permission to participate in some of the live simulation exercises conducted at the following sites:

- The Westfield Centre - Derby
- Rolls Royce Nuclear
- University of Derby Towers Building

As explained in Chapter 3, observations made during the above live simulation sessions were captured as a collection of field notes. As an example, Appendix 4.1 contains the field notes developed for the simulation exercise observed at the “Derby Westfield Centre.”

However, before making the selection, brief discussions with senior fire officers took place to understand the possible opportunities and constraints. These discussions revealed the following important considerations, which in combination helped in the selection of high-risk sites to develop the scenarios.

- Prior understanding and familiarity with the incident site would be an added advantage during the development and use of the scenarios.
- Access to the incident site or/and access to relevant documentation such as operational risk reviews and incident maps, photographs of the incident site would be valuable during the development and use of the scenarios.
- The number of scenarios to be used for an interview should not be large as it takes considerable time to explain and elaborate. Yet sufficient scenarios should be used to capture the holistic requirements and cover the aims of the fire and rescue operations.
- Sites should be selected in such a way that the fire officers taking part in this exercise have some experience of them. This may improve the quality of the data as well as may take less time for scenario elaboration.

Having considered the above factors and confirmed support extended by the DFRS, the following four sites were selected for scenario building.

- The Westfield Centre - Derby
- Rolls Royce Nuclear
- Bath Street Community Housing
- Derbyshire Royal Infirmary Nurses Quarters

The Westfield Centre was identified as the main incident site to be used for the purpose of data capturing. Being a state-of-the-art modern building, the Westfield Centre consists of:

- Businesses ranging from shopping malls, car parks, restaurants and a movie theatre.
- Floor areas ranging from basements, compartments, storage warehouses and open lobby areas.
- Occupants ranging from fire-trained staff to the general public with a variety of age limits, genders and cultures.
- Possible risks ranging from single compartment fires to the possibility of organised explosions and fires.
- Property ranging from high-value jewellery shops to small stationery outlets.

The Westfield Centre was recognized by most of the fire officers interviewed as the best choice for the principal scenario. However, the Westfield scenario has some limitations in covering some of the fire and rescue objectives, especially related to the environment and community, including risks related to chemicals or radioactive material. Therefore, it was suggested that a secondary scenario such as an incident at the Rolls Royce Nuclear facility should be introduced. Furthermore, the highly compartmentalized Royal Infirmary nurses quarters building was expected to introduce the dimension of fires in high-rise apartments occupied by well-drilled and disciplined tenants. Similarly, the Bath Street flats as a scenario was expected to bring the dimension of a community condominium occupied by less fire-drilled tenants including families, residents with disabilities and/or elderly tenants. Together, these four scenarios were expected to cover the overall operational scope of the DFRS in relation to large high-fire risk buildings.

After the above selection of primary and secondary sites, four scenarios representing fire emergency incidents with possible variations were developed with the aim of using them as the main interviewing probe during the application of GDIA. Each scenario was comprised of a detailed sequence of an incident built in the form of a story (Appendix 4.2). To improve the richness of the scenario content, operational risk review documents for that particular building supported by the relevant floor maps and photographs showing various locations of the site were incorporated. In addition to the main incident, each scenario included variations by shifting the location of the incident to different floors of the building, changing the time of the incident and addition/removal of a variety of risks. Such variations were expected to maintain the motivation of the interviewee so that the flow of the

interview becomes smooth and rich with useful data. To preserve privacy and security of the client data, DFRS only allowed the maps, photographs and the incident focused operational risk reviews to be used during the interview period. Therefore, publication of such documents is not allowed within the research write-up.

Confirmatory High-fire Risk Sites in Leicestershire

Since the LFRS was mainly used in the validation phase of this study, it was important to identify sites similar to those described in the scenarios developed for the case of Derbyshire. As explained in Chapter 3, secondary site selection was based on the sampling strategy: “Confirmatory Cases” (Patton, 2002). Such identification is important as it expects to motivate the participants during the validation sessions and encourage the discussion to become meaningful and consistent. Similar to the case of DFRS, initial face-to-face discussions with several senior officers of the brigade were held to identify the appropriate *confirmatory fire sites* located within the county of Leicestershire. The following high-risk sites were identified as similar *confirmatory fire sites* to those described in the scenarios developed for the case of Derbyshire.

- The Highcross (Shires) Shopping Mall Leicester
- Loughborough University Towers Building
- Leicestershire Royal Infirmary Hospital
- 3M Health Care

Confirmatory High-Fire Risk Sites in Nottinghamshire

Similar to the case of LFRS, the case of NFRS was used only for the purpose of validation. Therefore, the following high-risk sites similar to those described in the scenarios developed for the case of DFRS were identified.

- Victoria Centre - Nottingham
- Litmus Building
- Victoria Centre Flats
- “X” Manufacturers (Not allowed to reveal the true name)

As in the case of LFRS, this selection was also based on the “Confirmatory Cases” (Patton, 2002) strategy of sampling.

Scenarios were also developed for each of the sites selected in LFRS and NFRS. All these scenarios were equal to the scenarios of the corresponding sites in DFRS. However, compared to the scenarios developed for the case of DFRS, these were less comprehensive as they do not include the building maps, pictures and other related documentation due to restricted access to the sites and related resources.

4.5 Elicitation of Tasks of Fire Fighters during Fire ER Operations

Data gathering for the task capturing phase of the GDIA was successfully accomplished by carrying out eight interviews representing both novice and experienced firefighters from each of the four selected job roles. During the interviews, the scenarios described in Section 4.4 (Appendix 4.2) were used as the main prompting device to elicit tasks belonging to the specific job role.

This phase was designed to provide tasks for each firefighter job role. Such tasks were expected to probe interviewees in the remaining steps of the information gathering exercise. Capturing tasks is identified as a straight forward process compared to other phases. Firefighters find it much comfortable and easier to express and explain their operational tasks than any other aspect of their operations. Subsequent phases were expected to require a much higher number of interviews. Hence, it was decided to limit the number of task capturing interviews as a means of preserving the amount of access for the future interviews. However, obtaining appropriate and accurate tasks is expected to provide much greater flexibility and ease in conducting the goal eliciting phase. Therefore, the task gathering interviews were conducted with a small number of SMEs who have considerable familiarity with the incident scenarios including both experienced and novice firefighters. Investigations were made to identify the most appropriate personnel using the following criteria:

- Number of training/simulation experiences related to the incident scenarios.
- Number of real-time ER experiences related to the incident scenarios.
- Experience in the job role.
- Willingness and accessibility to conduct an interview.

Based on the above criteria, four experienced and four novice firefighters representing two appropriate participants for each job role were identified as interviewees (Appendix 4.3).

As explained in Chapter 3, a simple interview guide consisting of open-ended questions and prompts capable of maintaining the focus of the interviewees towards describing their tasks was developed (Appendix 4.4).

This consists of three types of probing elements:

- Four fire scenarios as the primary planned interview probes
- Open-ended specific grand tour question.
- Simple floating prompts and variations to the primary scenarios to facilitate continuous and meaningful discussion.

On average, each interview lasted 1.5hrs. Due to abrupt work commitments, several interviews were stopped in the middle of the conversation and had to be continued at a later time. All the interviews were tape recorded and later transcribed for the purpose of capturing the tasks belonging to each job role. References to fire and rescue documentation, such as various policy and procedure documentation, operational risk reviews and the observations made during various fire and rescue training and simulation sessions as an observer were also used to improve the interpretation of the tasks identified during the interviews.

Although the initial intention was to identify the list of tasks likely to be carried out during a large-scale fire, considering the higher amount of information gathered, it was decided to classify or categorize the tasks into meaningful categories (Dey, 1993). This not only reduces the level of abstraction during the analysis to a manageable level (Dey, 1993), but also expects to guide the next phase of the GDIA better. Prior to identifying the actual tasks, interview voice files were examined for identifying a classification guideline for the tasks. The following quotes have been identified as important to formulate a basis for the task classification.

Interviewee 1: *“Since we drive on our own as senior officers... from our initial roll call till arrival there are very limited things we can do”*

Interviewee 4: *“you can be a fire fighter, watch manager, station manager but as when you arrive after first two or three pumps you will have a bit of time till you being actually assigned for a specific job. This is a good opportunity to have our own assessment”*

Interviewee 1: *“when summoned as an IC we’ll first have our own inspection prior to take over the job”*

Interviewee 3: “you will have your own assessment before you commit yourself as an IC and takeover from the person currently in charge”

Interviewee 3: “As an IC you’ll have to be very dynamic and have to do a lot of fire fighting yourself to do your organizing and planning before you completely settle down, then only we can take a step back and have a much more overall view”

Interviewee 4: “As ICs we’ll become much more relaxed when things get stabilized, then only we can take a step back and get an overall view”

Interviewee 3: “After fire being stabilized and when you have much more control over the operations either you scale down the operations yourself or you can hand over it to some senior or junior officer depending on the progress of the operation”

Interviewee 4: “as a SC when you have certain control over your targets and when fire is controlled you start thinking releasing your resources in the sector and slowly winding up operations in your sector”

Apart from the above comments, as explained in the Fire Service Manual Volume 2: Incident Command (2008), any type of fire usually follows three operational stages:

- Initial Stage
- Development Stage
- Closing Stage

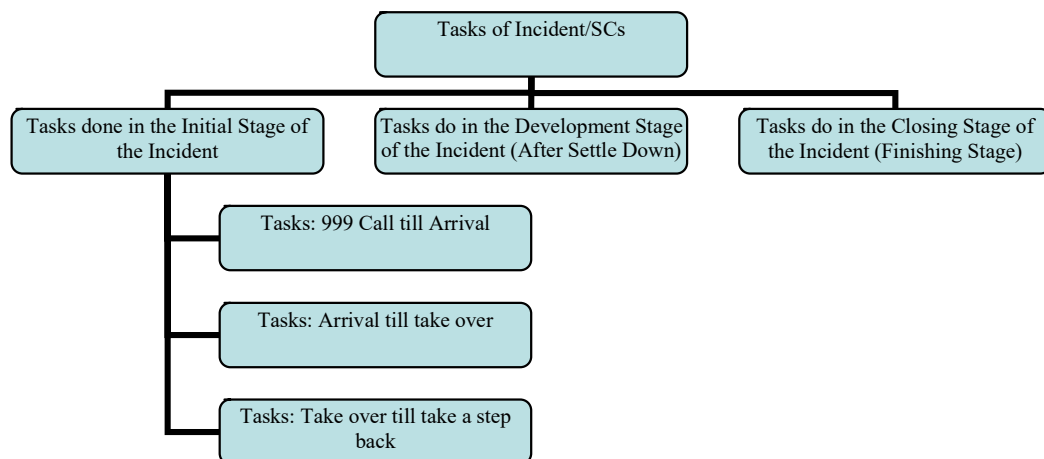


Figure 4.5: Classification of ICs/SCs Tasks

During the initial stage of the incident, officers carry out their initial risk assessment to evaluate the situation tasks and risks. Based on that, officers tend to select a possible safe system. During the development stage, commanders look for further delegation and

deployment of tasks and resources. Finally, in the closing stages, commanders try to maintain control of the incident that has been gained. At this stage, they also look for the welfare of crews and scale down of the operation. Furthermore, depending on the level of control, the job would be transferred to a senior officer. The above analysis suggests a task classification for both the ICs and the SCs based on the incident progress of an incident as shown in Figure 4.5.

For frontline firefighters and their entry control officers, the following remarks made during the interviews were identified as important for a suitable classification of tasks.

Interviewee 5: *“Before arrive we are looking to prepare both physically and mentally ourselves for the job to be done”*

Interviewee 6: *“As fire fighters who deploy in fire a tender, our job starts just after a 999 call receive to our control. Specifically, as when our fire station receive a call for attendance, which usually is based according to a pre defined attendance rota”*

Interviewee 5: *“As BA entry control officers, especially after arrival we’ll have our own observations to have a better understanding and preparation till we get deployed in our actual job as a BAECO”*

Interviewee 8: *“Always just after arrival and between operations we like to take a breather to look and observe current situation from our own eyes and prepare ourselves better for the next job”*

Interviewee 7: *“As a BAECO we are in a grater rush, especially when we deploy fire fighters into the incident. But when they went in we become much stable and will have some time for our own to figure out what is actually going on and to think about it”*

Interviewee 5: *“At some point of time we may have to close the BA operations from one particular BA entry point due to the completion of assigned jobs or some times, we may have to get a toilet break or longer relief due to long hours of work”*

Interviewee 6: *“After getting deployed by a BAECO, as a team, we have to look after all the tasks on our own till we finish the jobs, that is when we come out from the risk environment hand collect our tallies back”*

Considering the above remarks and the classification described in the Fire Service Manual Volume 2: Incident Command (2008), the division of operational progress of BA operations is similar to that of their senior officers and can be interpreted as the initial stage, development stage and closing stage. The only difference here is that it is more focused on

specific operations, whereas in the classification of the IC, it is based on the progress of the whole incident. Therefore, the classification for BAECO is shown in Figure 4.6, whereas BA wearer classification is shown in Figure 4.7.

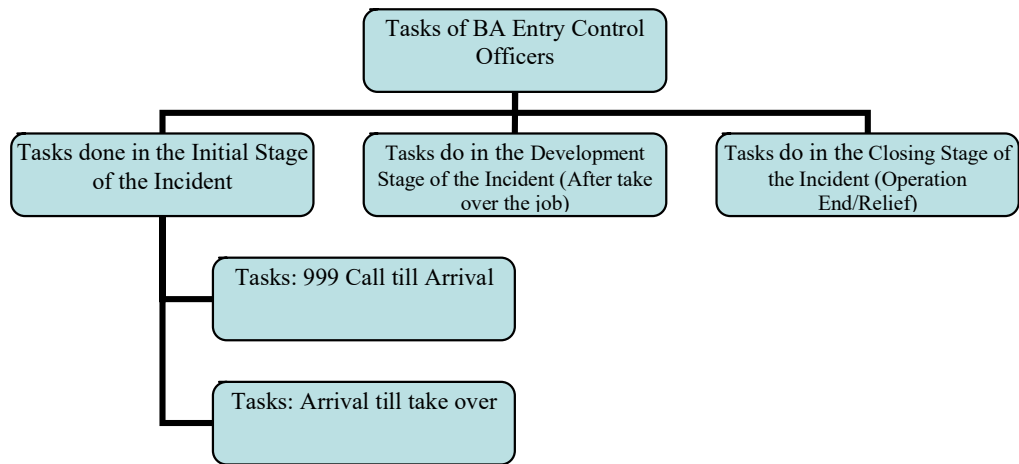


Figure 4.6: Classification of BAECOs Tasks

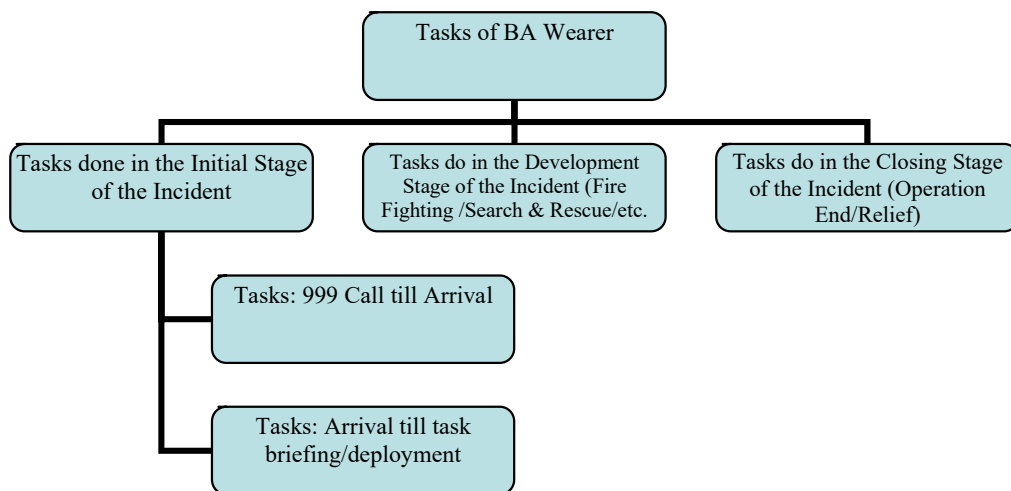


Figure 4.7: Classification of BA Wearer's Tasks

4.5.1 Analysis for Task Elicitation

As explained in Chapter 3, task elicitation was based on the constant comparison technique (Boeije, 2002). At first, interviews were examined to identify *Task fragment*. A *Task fragment* can be a word; a set of words, a complete statement or set of statements that display a satisfactory level of characteristics to represent an underlined theme of a meaningful task. These *Task fragments* are expected to represent the tasks relevant to that particular job role during an incident. During this activity, the conversation parts of each

interview were separated out as *Task fragments*. This involved close reading and line-by-line analysis of the interview (Boeije and Van Doorne-Huiskes, 2003).

The *Task fragments* were first identified from the interview transcription of the experienced officer, and then the second interview transcription belonging to the novice officer was examined to capture the *Task fragments* carrying the same or similar themes. Thereafter, similar *Task fragments* of each interview were tabulated in parallel for better illustration. Later, the interview given by the novice officer was re-examined for any additional but meaningful *Task fragments*, which had not been described by the more experienced first interviewee. As most of the fire and rescue policy and procedure documentation focuses on tasks, references made to fire and rescue documentation were used as an additional source of triangulation during the application of constant comparison technique (Boeije, 2002).

The documentation available also provided invaluable evidence for quick and easy identification of tasks of various firefighter job roles. Observations during training and fire scenario exercises also lead to identify additional task related evidence in the form of document sentences and field notes (Appendix 4.1). Later, these were matched with the previously captured *Task fragments* and listed parallel in a separate column. This additional task related information not only strengthened the findings of *Task fragments* but was very useful for interpretation of firefighter tasks from the identified *Task fragments*.

The second activity in the task elicitation process consisted of interpreting the parts as a whole by connecting the matching task fragments to form a task of a particular firefighter. This was repeated for each case of matching data parts to obtain a list of tasks belonging to a particular firefighter job role.

Table 4.1 shows the exercise of task analysis for an extract of the task fragments and corresponding interpretation of tasks elicited for the IC job role. Similarly, tasks analysis related to the remaining job roles were also completed. As an example, a comprehensive list of important tasks of an IC is shown in Appendix 4.5.

Table 4.1: An Extract of Task Fragments and Interpretation of Tasks for the Incident Commander Job Role

| Task Fragment – Interviewee 1 | Task Fragment Interviewee 3 | Fire and Rescue Policy and Procedure Documents | Observation of Live Scenarios / Trainings | Interpretation of Task |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| After taking over the role of IC, task that I immediately carry out is my formal dynamic risk assessment | Without delay, as an IC a major task I have to carry out is the incident wide risk assessment | Dynamic Risk Assessment (Incident Command Fire Service Manual,2008) | | Carry out Initial Dynamic risk assessment |
| Based on my assessment then I will change the plans already implemented by the previous IC | Outcome of the risk assessment will help me to do necessary adjustments of the plans or if required to formulate new operational plan | | | Formulating or amending incident plan |
| I like to read the hazmat data | I may get hazmat information via control or from the Modas | | | Access Hazmat Data |
| Similarly, I have to always think about the resources. I have to identify the new resource need and therefore, need to order them through my command support team | One of my other priority tasks would be to evaluate the available resources and identify the new requirements to deploy the operational plans. Also, I'm responsible for the task of ordering of such resources | | | <ul style="list-style-type: none"> • Resource assessment • Identify new requirements • Request new requirements via command support |
| For proper task deployment it is always important for me to develop the incident hierarchy. | I have to quickly identify the layout of the incident hierarchy for different tasks. It is simple but important. Later with the IC progress we may develop more complex structure | | As soon as an officer is appointed as an IC he quickly assigned the sector commanders for the fire sector and Search and Rescue Sector.(Rolls Royce – Field Note Ref: 1.11) | Build Basic IC Structure (Not Comprehensive Structure with complete sectorisation) |
| Again based on my investigations I have to quickly identify the tasks of the plan to be carried out and I have to deploy them among correct officers | I have to divide bigger tasks to smaller ones and have to allocate them among my officers | | | Task allocation |
| As an IC one the critical tasks would be to announce the correct tactical mode | Communication of correct tactical mode is very important | | Change of tactical mode from delta offensive to delta defensive is informed to sector commanders via radio (Westfield fire training – Field Note Ref: 1.8) | Communicate the tactical mode |
| It is always important to report back my major decisions to the control | I have to always update control about my decisions | Advice MACC via Command Support giving name & role of IC and state. The current Tactical Mode (West Yorkshire standard operating procedure No.18,Incident Command System Revised December 2007) | | Start Passing the decisions back to control |
| Before come with my own plan I always compare my incident picture with what I heard from previous commander | Comparison of my own interpretation of the incident and what had been told by the IC before me | | | Compare your own picture with the picture getting from the officer in charge |
| After request I may have to keep an eye on resources I expected to receive. Also, I may need to order new resources | Time to time to know what is happening to my requested resources | The Incident Commander must ensure that adequate resources are available and that arrangements have been made to control them (Incident Command Fire Service Manual,2008) | Ask command support to order high volume water pump (Westfield fire training – Field Note Ref: 1.10) | Monitor the status of ordered resources. Request any additional resources and monitor their arrival |

| | | | | |
|--------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--|-------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| It is also important to advise and discuss with my commanders about how to implement the operational plan whether it is new or modified. | I will ask my colleagues to carry out our plans related to the operations | | | Discuss/Advice other commanders to carry out the plans |
| As an IC I may have to set up the bridgehead, especially if I'm the first one to take over. Similarly, setting up of the lobby sector initially. | At the beginning, I have to demarcate an area for the bridgehead and the lobby sector | Instructions for Sectorisation and Establishment of an Incident Cordons of incidents (Standard Operating Procedure Note 35, Incident Command, Derbyshire Fire and Rescue , April. 2007) | | <ul style="list-style-type: none"> • Setup bridge head • Setup Lobby sector |
| Immediately as an Incident commander I have to set up the safety cordons | Prior to decide the tactical mode it is important to identify different zones of operation. Usually Inner and outer cordon. Inner cordon cover the boundary of most hazardous area | Instructions for Sectorisation and Establishment of an Incident Cordons of incidents (Standard Operating Procedure Note 35, Incident Command, Derbyshire Fire and Rescue , April. 2007) Cordons are employed as an effective method of controlling resources and maintaining safety on the incident ground. Can be inner cordon and outer cordon (Incident Command Fire Service Manual,2008) | | Setup Safety zones (cordons) |
| One of the initial tasks may be to setup the essential fire fighting, rescue and ventilation jobs as quickly as possible | Initiation and monitoring task such as actual fire fighting, salvage ventilation and rescue would be my prim tasks | | | Initiation and monitoring <ul style="list-style-type: none"> ▪ Fire fighting ▪ Salvage ▪ ventilation |
| Especially in the early stages I may have to setup the BA teams. But later I may have to include them in to the operational plan | If I'm the first one to arrive I may have to look for required amount of BA teams and its formation | | | Set up BA teams |

Although classified into various operational phases, careful study of the tasks identified indicated the possibility of carrying out a particular task or its variant in a different operational phase depending on the progress and contextual change of an incident. For example, as listed in Appendix 4.5, two of the tasks identified under the operational phase “After Settle Down” for the job role IC: 1) Talk to building inspectors from the local authority and 2) Talk to safety officers are considered. Usually these tasks are carried out after an IC is settled down in his job. However, there is always a possibility he/she may need to carry out the same tasks depending on the situation prior to settle down or even in the closing stage of an incident. This was justified by the following comments of Interviewee 1.

.....You see as an IC we usually talk to either building inspectors or our safety inspectors only when we are settled in the job and only after we have managed to looked after all other important things.....But... you never know if the building is old and if we had some feeling it might collapse soon, the same tasks may have to carry out much earlier....

may be before doing anything else.....Similar situation can occur even when we come to the closing stages of an incident.

4.6 Elicitation of Goals of Fire Fighters during Fire ER Operations

As described in Chapter 3 in relation to the GDIA procedure, goal identification interviews were carried out by having face-to-face interviews with firefighters. Since this phase of the interviews was aimed to formulate the basis or core of the GDI diagrams leading to the elicitation of the firefighter's information requirements, the numbers of participants selected from each job role were increased. Higher number of interviews reduces unnecessary bias. It further increases the level of completeness in terms of the number as well as the scope of the data elements to be captured. Therefore, four officers representing each of the four selected job roles were interviewed. Participants for each job role were selected in such a way that they represent both experienced and novice categories. During the selection process, both experienced and novice firefighters were given an equal opportunity. Therefore, equal numbers were selected from each of the two categories for the interviews.

During a single case study, there is always a possibility of bias due to the lack of variety of the selected sample. Therefore, to minimize the interior bias in the data to be captured, participants were selected from different areas of the county. This captured the viewpoints of firefighters located in both urban and rural areas as well as firefighters representing the categories of *full-time* and *retained*. Appendix 4.6 shows the list firefighters selected based on the above criteria. Similar to the task elicitation phase this particular set of interviews was also carried out with the SMEs selected from the Derbyshire FRS.

Interviews in this phase were focused on identifying the goals to be achieved by the selected interviewees during the operations described in the scenarios. Therefore, as explained in Chapter 3, semi-structured interview guide (Leech, 2002) consisting of specific open-ended questions and prompts (McCracken, 1988) was developed (Appendix 4.7). This guide helped to maintain the focus of interviewees towards their goals during the interviews. The interview guide consists of three types of probing elements:

- Four fire scenarios as the primary planned interview probes.

- Open-ended specific grand tour questions developed with the use of tasks identified during the 1st phase of the GDIA.
- Simple floating prompts and variations to the primary scenarios to facilitate continuous and meaningful discussion.

Before the commencement of an interview, a brief introduction was given to each participant in relation to the expectations of this particular interview and an explanation of what is expected as goals. Furthermore, each participant was briefed on the importance of this particular phase of interviews with respect to the expected outcome of the study. Participants who had not participated in a previous interview session were motivated by explaining how they could benefit from the outcomes of this study. After the initial introduction, participants were introduced to the four scenarios. SMEs were then asked to describe their expected motives with the aid of previously identified tasks classified into different operational phases of the response operation. Participants were also encouraged to describe their desires, obligations and norms to be achieved or motivations during other similar ER situations. Such probing combined with the specific tasks and relevant emergency scenarios lead participants to describe their goals during their response work. Variations to the scenarios were introduced appropriately during the interviews to obtain finer details and to extract more cognitive information relevant to each job. On average, duration of the interviews was 1.5hrs. Similar to the task elicitation phase, several interviews were interrupted in the middle of the conversation due to emergency work commitments of the participants. These interviews were re-arranged and continued at a later date. All the interviews were tape recorded and later transcribed. Later, during the analysis phase, transcriptions were used to extract any possible goal related statements: *Goal fragments* described by participants.

During this step of the GDIA exercise, the FRS granted permission to participate in two of their important training programs. One was Breathing Apparatus training with simulated fire and rescue exercises for novice firefighters. The other program was an Enhanced Incident Command training course to improve the performance of ICs and SCs. During these programs, important training moments were captured as appropriate field note descriptions. In parallel, verbal communication was recorded whenever allowed and feasible. Verbal communication included face-to-face discussions as well as the radio-talk between firefighters. Important training materials were also accessed and collected.

Furthermore, as a part of the ethnographic field work video clips or photographs (Pink, 2007) were also taken using a hand held camera. Later, these materials were catalogued so that information related to each and every observation can be easily accessed at a later occasion.

4.6.1 Data Categorisation

The enormous amount of data captured meant, it was essential to identify a meaningful classification or categories (Dey, 1993) prior to identifying the goals of firefighters. Therefore, interview voice files were examined to identify a guideline for the classification of the goal related statements (*Goal fragments*). Initial investigation was conducted with the aim of verifying the viability of applying the classification used in task capturing for goal capturing classification as well. However, careful examination of the interview voice files suggested that it is not feasible to use the same classification corresponding to the job roles of IC and SC due to possible information overlapping between the categories. Both SC and IC task related statements were classified into five different categories based on the operational progress. However, the initial investigation of interview voice files suggested that it is not always feasible to classify some of the goal related statements into three different categories namely *Take over till take a step back*, *After settle down* and *Finishing Stage*. This was because most of the statements made by the interviewees did not clearly indicate whether they should belong to a particular operational phase, especially after assuming their duties. There was some evidence of possible repetition of goals, given the possibility of achieving the same goal in single or several operational phases. Therefore, it is not feasible to classify them exclusively into one particular operational phase. Having considered the above, findings corresponding to the job roles of IC and SC lead to a much simpler classification consisting of the following phases:

- Before Arrival – On Arrival
- After Arrival till takeover
- Take over till finish of operations (*By combining previous task categories: Take over till take a step back, after settle down and Finishing Stage*)

However, for the job roles of BA and BAECO it appeared that the classification used in capturing tasks is equally suitable for the elicitation of goals. Therefore, it was decided to maintain the same classification used for task identification for the job roles of BA Wearer and BAECO. The complexity of the activity of capturing goals and sub goals is high, since

it was considered useful to identify both a goal as well as its suitable position in a hierarchy of goals. This led to the introduction of an additional category called *General comments on the order of the goals/link in-between different goals*. Goal fragments related to comments on the level of hierarchy and how they are being linked to other superior or sub goals were captured under this category. It must be mentioned that this particular classification of goal related statements is only to reduce the complexity of the analysis. This analysis does not intend to classify or categorize the goals of firefighters strictly into a particular period or operational phase as there is always a possibility that the goals identified in one particular operational phase become important in a different phase depending on the changing nature of the emergency.

4.6.2 Analysis for Goal Elicitation

The goal structure belonging to a particular firefighter job role was developed in a sequence of several steps (Figure 4.8). At first, *Goal fragments* representing specific *categories* relevant for a particular job role were identified. During this step, any description indicating the hierarchical levels of the goals was ignored. The constant comparison technique (Boeije, 2002) practiced during the task capturing phase was also used for this particular activity. As the second step, efforts were made to filter out the *Goal fragments*, which represent the *top most goals* of that particular job role. As the third step of the analysis process, the classified *Goal fragments* representing the *top most goals* were connected together to be interpreted as a whole for that particular job role.

Later, by selecting each top-level goal separately, *Goal fragments* that strictly related to the sub goals of that particular top-level goal were captured by filtering them into the relevant categories. This was followed by the interpretation of the fragments to form suitable sub goals for that particular higher-level goal. The same procedure was followed for the rest of the top-level goals. Finally, the above process was repeated to identify any other emerging lower-level goals corresponding to each emerging sub goals. The goal structures relevant to all the four job roles were developed by adopting the analysis process set out above.

Only a small section of the goal structure belonging to an IC is chosen to describe the details of goal-capturing process since the analysis carried out for the development of goal structures for the entire job roles was complex and lengthy.

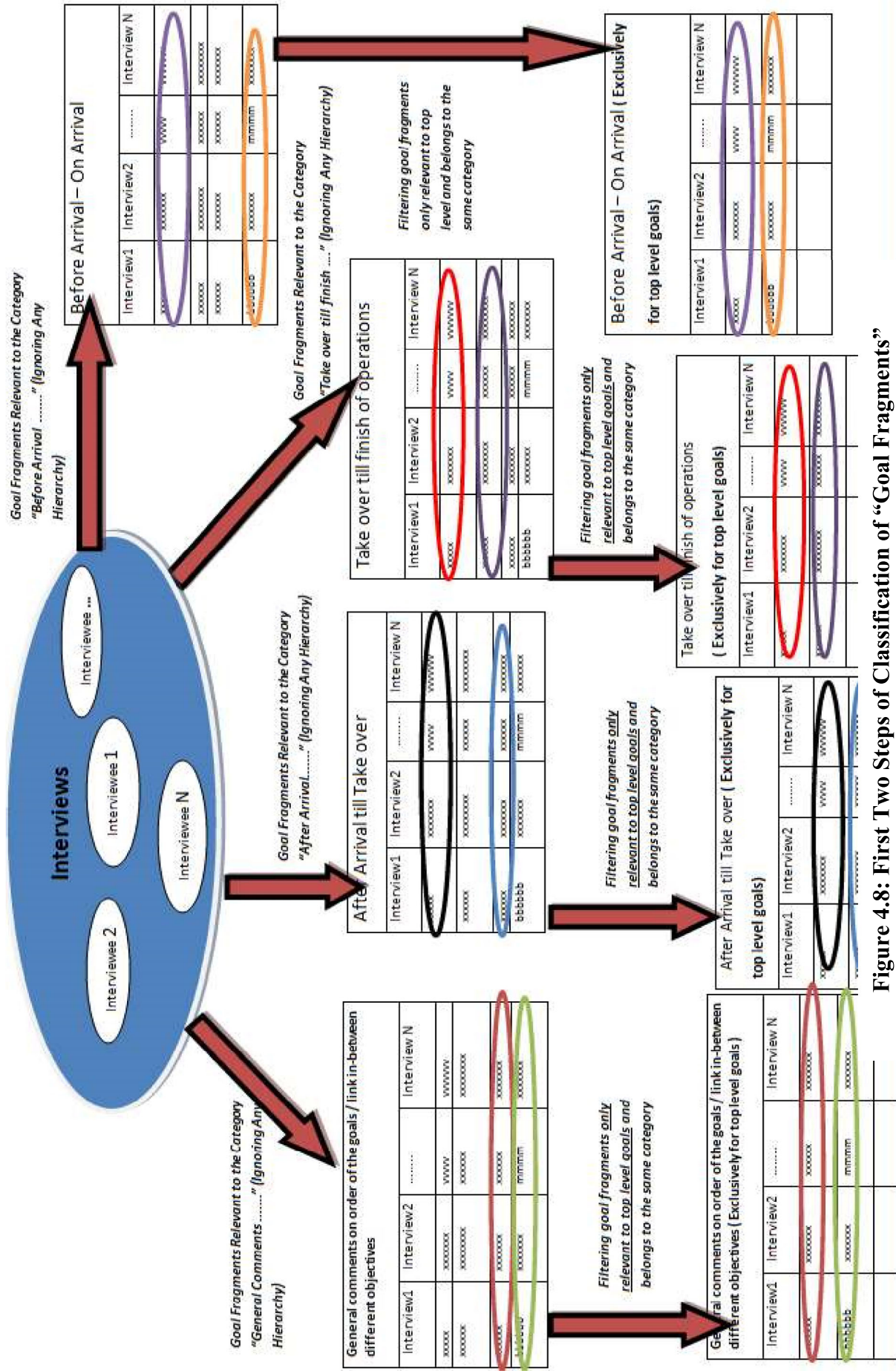


Figure 4-8: First Two Steps of Classification of "Goal Fragments"

4.6.3 Elicitation of the Primary and Secondary Level Goals of an IC

At first careful study of interview data of four participants, representing ICs lead to the *Goal fragments* representing the IC job role being classified under four categories:

- Category 1: General comments on the order of the goals / links between different objectives.
- Category 2: Before Arrival – On Arrival.
- Category 3: After Arrival till takeover.
- Category 4: Takeover till finish of operations.

Later, the captured goal fragments of each of the categories were carefully re-examined. As shown in the Appendix 4.8.1, 4.8.2 and 4.8.3, such referencing lead to the development of three “Coding Grids” consisting of extractions of the Category 1 and Category 3 and Category 4 type of *Goal fragments*, which exclusively describes the topmost goals or objectives of an IC. These “Coding Grids” consist of goal fragments expressing the same or similar meaning obtained from different interviewees representing the job role of an IC, extracts from the fire and rescue documentation and the researcher’s own observations. In this particular situation apart from the ”Coding Grids” consisting of Category 1 , Category 3 and Category 4 fragments, there were no further fragments found relevant to the top-level goals under the Category 2.

4.6.4 Mapping Goal Fragments to Primary and Secondary Level Goals

Mapping of Goal Fragment Reference 1.1

The *Goal fragments* obtained were mapped and interpreted appropriately to form the Primary and Secondary level goals of an IC. The fragment reference 1.1 of the coding grid (Appendix 4.8.1) consists of three *Goal fragments* obtained from Interviewees 1, 3 and the Fire Service Manual Volume 2: Incident Command (2008). These fragments captured under the reference 1.1 were mapped to form the highest level goal of an IC by interpreting the meaning of the three fragments together as “*Assure health, safety and welfare of humans, property and environment*” (Figure 4.9).

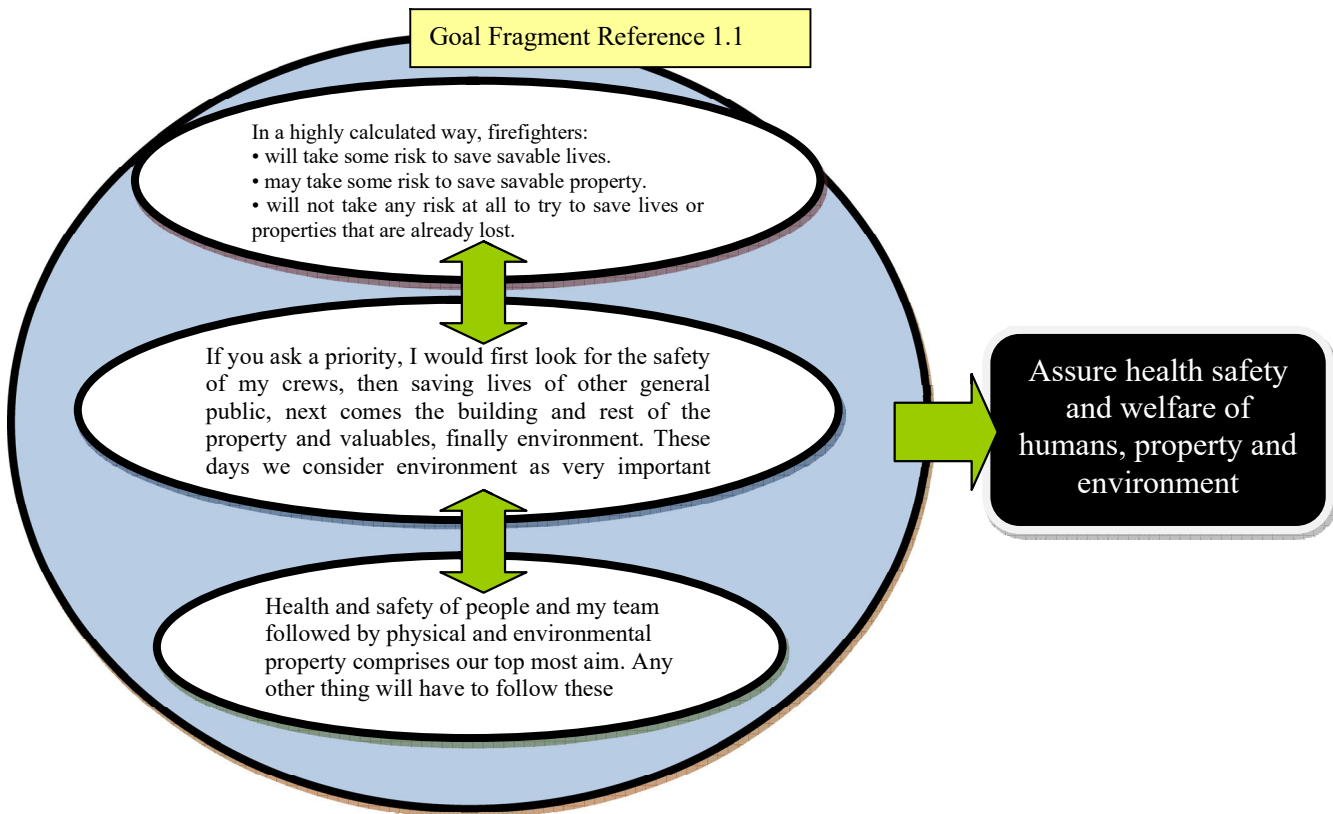


Figure 4.9: Mapping of Goal Fragment Reference 1.1

The statement of Interviewee 3 in the fragment reference 1.1: “*Any other thing will have to follow these priorities*” and the observations made during the fire training and simulation activities suggest that this is the overarching goal and that all the other goals explored should form a sub-set of that overarching goal. With such a perception, the rest of the fragment references shown in the Category 1 (Appendix 4.8.1), Category 3 (Appendix 4.8.2) and Category 4 (Appendix 4.8.3) consisting of goal fragments expressing the same or similar meaning obtained from various sources were mapped to form several sub goals of the topmost goal interpreted above. The second level goals obtained after such interpretation are as follows.

Mapping Goal Fragment Reference 1.2

- Ensure Health Safety and Welfare of Firefighters

Mapping Goal Fragment Reference 1.6

Observations made during various fire fighting training sessions and fire scenarios suggested that there are two major parties that can be affected during an incident. Personnel

who are directly affected due to the incident and therefore, located within the designated hazard cordons of the incident premises is defined as the main category. They are often called “casualties.” The general public who remain outside the incident premises and beyond the designated hazard cordons but who could still have a potential risk or impact from the incident are defined as the second category. Importantly, the health, safety and welfare of these two categories are being served via different fire and rescue operation and control procedures. Due to such operational differences, it was decided to map these two parties into two different goals as illustrated below.

- Ensure Health Safety and Welfare of Casualty
- Ensure Health Safety and Welfare of General Public

Mapping Goal Fragment Reference 1.7

It was decided to interpret “Environment” and “Property” as two separate goals since the operational practices applied to save them appears to be different according to the published fire and rescue documentation (Fire Service Manual Volume 2: Incident Command, 2008) and the observations made during the field study.

- Ensure Minimum Damaged to the Property
- Ensure Minimum Environmental Damage within the Incident and Nearby Surroundings

Mapping Goal Fragment Reference 3.1

- Ensure Appropriate Commitment as an IC

Mapping Goal Fragment Reference 4.1

- Ensure Post Incident Considerations

Mapping Goal Fragment Reference 4.3

- Ensure Appropriate Handover of Responsibilities

4.6.5 IC Goal Structure - Primary and Secondary Level Goals

The above identified top most goal and its 8 immediate sub goals were classified into two different levels: Level 1: Primary and Level 2: Secondary (As shown in Figure 4.10).

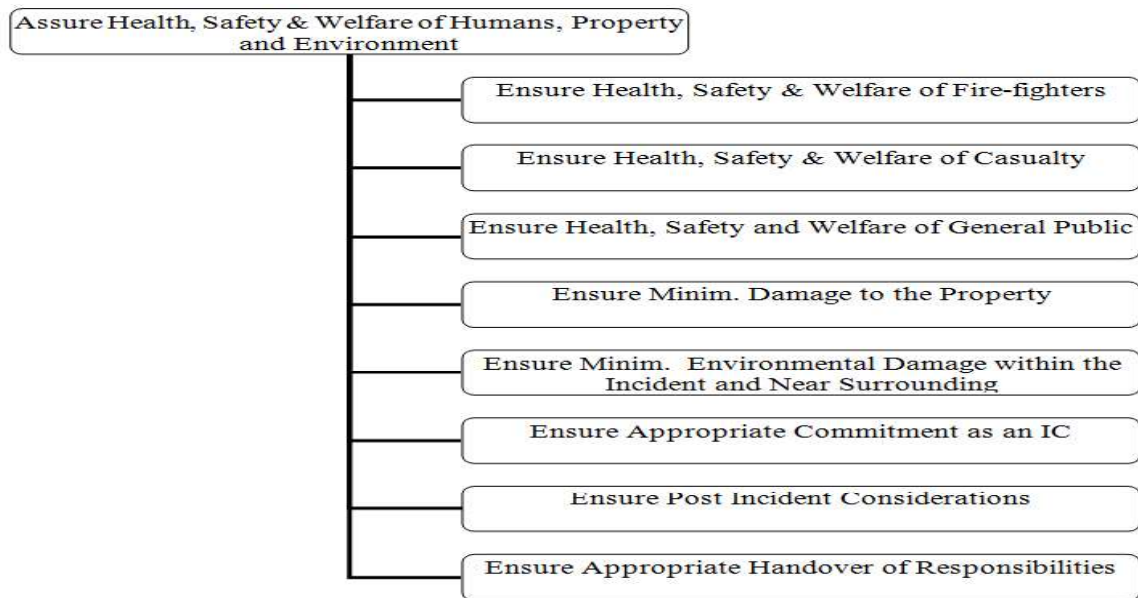


Figure 4.10: Primary & Secondary Goals of an IC

4.6.6 The Tertiary and Lower Level Goals of an IC

Previously obtained primary and secondary goals were extended to represent the subsequent lower-level goals of an IC. During this exercise, each secondary goal identified above was expanded into its own lower-level goals. During this exercise, similar principles used in obtaining the primary and secondary goals were maintained.

4.6.7 Development of the Sub goal Structure Representing the Secondary Goal

“Ensure Appropriate Commitment as an IC”

Explaining the development process of all eight secondary goals structures would be complex and lengthy. Therefore, the secondary goal of an IC *“Ensure Appropriate Commitment as an IC”* is selected at random for in-depth illustration.

At first, all the goal fragments captured for the IC job role, classified under four different categories were re-examined to extract the goal fragments, which exclusively refer to or describe the secondary goal *“Ensure Appropriate Commitment as an IC.”* Later, those obtained goal fragments were appropriately mapped to form the sub goals that should be reached to achieve this particular goal. Goal fragments were further examined to identify and map any further lower-level goals related to any of the above identified sub goals.

As the first step of eliciting the relevant tertiary level goals, the captured goal fragments representing the IC job role were carefully re-examined. As shown in Appendix 4.8.4, 4.8.5 and 4.8.6, such references have led to several additional “Coding Grids” of the Category 1, Category 2 and Category 3 to be formed. These “Coding Grids” primarily consist of the goal fragments that were assumed to describe the particular secondary goal. Later, the goal fragments captured in the “Coding Grids” were mapped to form the tertiary goals of the particular secondary goal. This led to the following tertiary goal structure of “Ensure Appropriate Commitment as an IC.”

Mapping Goal Fragment Reference 2.7

- Ensure Receipt of Incident Knowhow (Contextual)

Mapping Goal Fragment Reference 3.13

- Ensure Receipt of Knowhow on deployed controls and measures

Mapping Goal Fragment Reference 3.14

- Ensure accurate assessment of operational progress

There was a doubt whether the goal interpreted from the fragment reference 3.13 is a sub goal generated from the fragment 2.7. However, the Category 1 goal fragment 1.13 indicated that both goals should be positioned at a similar level of the goal hierarchy. The three goal fragment references 2.7, 3.13 and 3.14 lead to the first level sub goals of the goal “Ensure Appropriate Commitment as an IC,” which can represent as in Figure 4.11.

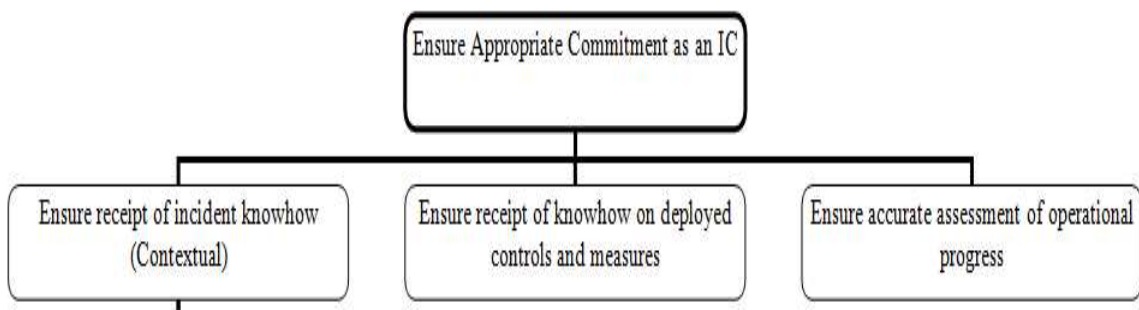


Figure 4.11: Sub goals of Secondary Goal: Ensure Appropriate Commitment of IC

Furthermore, with reference to the goal fragment reference 1.15, it was evident that the tertiary goal “*Ensure Receipt of Incident Knowhow*” can be further expanded into another subsequent layer of goals as follows.

Mapping Goal Fragment Reference 2.8

- Meaningful on the way and on arrival input of incident related knowledge

Mapping Goal Fragment Reference 3.12

- Meaningful on arrival self observation

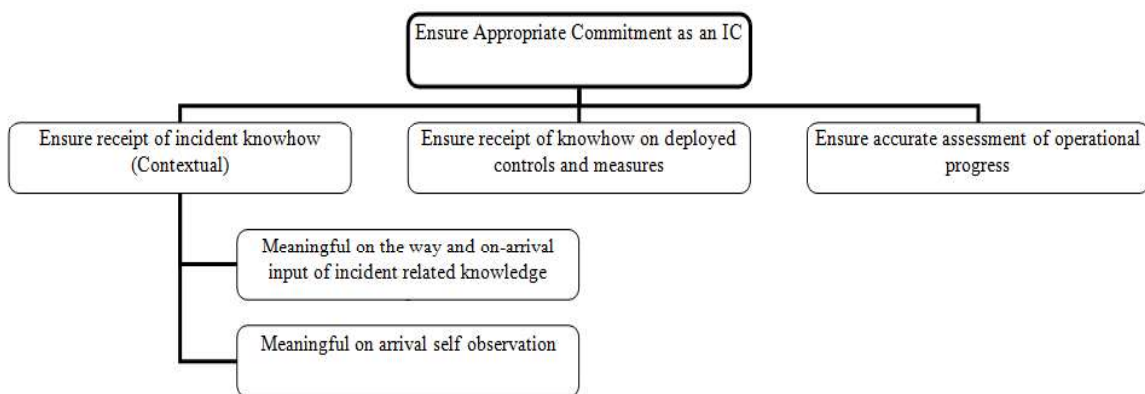


Figure 4.12: Sub goals of Secondary Goal: Ensure Appropriate Commitment of IC

As shown in the Figure. 4.12, the two sub goals “*Meaningful on arrival self observation*” and “*Meaningful on the way and on arrival input of incident related knowledge*” lead to an extension to the goal structure of “*Ensure Appropriate Commitment of IC.*”

Furthermore, it was evident that the combination of fragment references 2.9, 2.10 and 2.11 represent further lower-level sub goals of the tertiary goal “*Meaningful on the way and on arrival input of incident-related knowledge.*”

Mapping Goal Fragment Reference 2.9

- Look for appropriate operational notes

Mapping Goal Fragment Reference 2.10

- Look for accurate incident specific local knowledge

Mapping Goal Fragment Reference 2.11

- Ensure Navigation Guidance.

Mapping Goal Fragments Reference 2.23 and 3.19

- Ensure knowledge of casualty status

Importantly, in relation to the goals interpreted from the fragment references 2.9 and 2.10, the researcher understood some ambiguity that each of them may not clearly describe the underline goal and instead describe more of a task. As explained in Section 3.6.8, 5th Step of the GDIA application procedure, there is always a possibility that initial goal diagrams may carry goals with some ambiguity. However, at this stage of the study it was expected that these issues would be clarified and discussed during the goal validation sessions and participants of those sessions would propose appropriate modifications to minimize such ambiguities identified in the initial goal structures.

The completed sub goal structure representing the Secondary Goal: “*Ensure Appropriate Commitment as an IC*” is illustrated as in Figure 4.13.

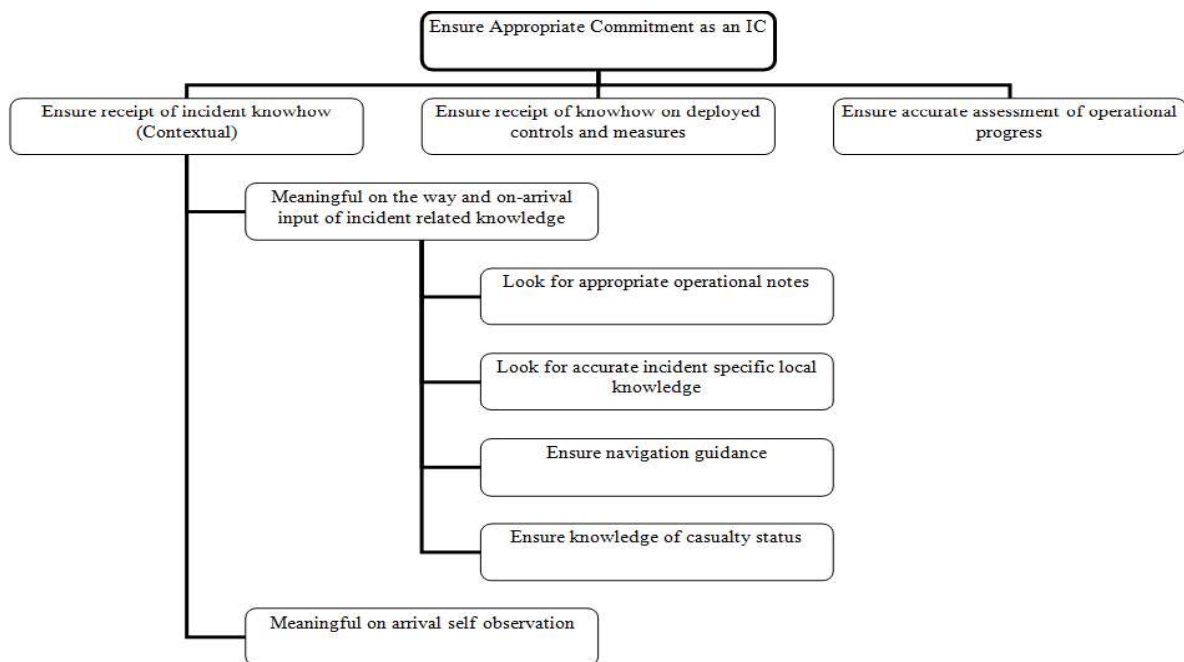


Figure 4.13: Goal Structure of Secondary Goal “*Ensure Appropriate Commitment as an IC*”

4.7 Goal Validation

The accuracy and appropriateness of the elicited goals have a direct impact on the success of obtaining the information requirements as these goals become the interview probes of the

next step of the GDIA process. Therefore, validation of the developed goal structures is considered to be vital.

Validation of the goal structures was carried out in two stages. In the first phase, the goal structures were sent back to the SMEs who participated in the goal capturing interviews with the request that they should add their comments onto the goal structures. In the second phase of the validation, the goal structures were validated with the use of feedback obtained from the SMEs who were non participants in the GDIA exercise. Feedback from both phases was later integrated to carry out necessary modifications to the initial findings.

It was decided to conduct the second step of the validation process in the form of face-to-face brainstorming sessions because of constraints such as time and accessibility. The participants for the brainstorming sessions were selected in such a way that each of them has either real-time experience in large-scale high-risk fires or were expert trainers in that particular job role. The selected participants are listed in Appendix 4.9. Five validation sessions were carried out for each job role of IC and SC. Furthermore, three validation sessions were carried out for the job roles of BAECO and BA Wearer, respectively. Each participant was met twice as all the participants were new to the exercise of validation. In the first meeting, each participant was introduced to the goal structures obtained earlier. Furthermore, the questions and concerns related to the presentation format or terminology of these goal structures were also clarified. Then they were asked to go through the goal structure and familiarize themselves with the goal descriptions. Later, a second meeting was held to capture their feedback on the goal structures. On average, the introductory sessions were limited to a maximum of 45min., whereas the subsequent actual validation sessions were extended up to 1.5hrs. During these secondary brainstorming sessions, participants were asked to describe their feedback freely on the developed goal structures. Participants were able to provide comprehensive feedback since they were given enough time to familiarize themselves with the goal structures prior to each brainstorming session. When necessary, scenarios were appropriately used to probe the participants. All the brainstorming sessions were tape recorded. These unstructured brainstorming sessions allowed the participants to suggest many other goal related descriptions apart from identifying what to include and what to delete from the goal structures. Freedom of expression during the brainstorming sessions meant much unrelated information as well as many useful comments leading to improvements in the goal structures. This was clearly

evident when listening to the recorded voice files of the sessions. Therefore, it was decided only to capture useful discussion points into the transcription rather than transcribing an entire session.

Each brainstorming session was captured as a selective transcript. Relevant written comments from the participants of the initial goal capturing interviews were also captured into a similar type of format. The constant comparison technique (Boeije, 2002) was useful in the process of transcript preparation. To avoid the omission of useful information and minimize the capturing of unrelated data, the following processes were used.

- The text with selective transcript was captured discussion points and written comments only relevant to the previously identified goals. The relevant goal is noted alongside each comment.
- Discussions points and written comments were tabulated only if they described or related to the following topics:
 - a. Discussion points and written comments directly highlighting the suitability of a specific goal.
 - b. Discussion points and written comments, which validated the accuracy and relevance of the description and/or interpretation of the obtained goals in relation to a particular job role.
 - c. Discussion points and written comments, which suggest the addition of new goals.
 - d. Discussion points and written comments, which seemed to be useful for improving the overall steps of GDIA.

Thereafter, these description fragments of the transcripts were compared to carry out the necessary changes or modifications to the developed goal structures. These comparisons were based on the constant comparison technique (Boeije, 2002). Changes to the goal structures were considered only if they were recommended by several participants. On some rare occasions, feedback of just one participant was also considered if the feedback was sufficiently meaningful and logical to carry out further amendments to the goal structures. The relevance of such comments was checked using the fire and rescue documentation and by revisiting the transcriptions of previous relevant interviews carried out during the task identification and goal identification phases.

Meaningful feedback obtained from both previous participants and non participants of GDIA during the validation improved the descriptive and interpretive validity of the goal structures captured. These goal structures were discussed among SMEs of the county of Derbyshire as well as the nearby counties of Leicestershire and Nottinghamshire. Validating the results in different counties increased the level of generalisability of the findings. Therefore, the validated goals become a step closer to representing the requirements of UK firefighters.

4.7.1 Validation of IC Goal Structures

To explain the flavour of the validation process, a specific part of the goal structure belonging to the job role of an IC is selected. In the previous phase of the study, the secondary goal *“Ensure Appropriate Commitment as an IC”* was chosen, so to maintain continuity and consistency, the same secondary goal is used to illustrate the goal validation exercise. Several important general comments given in relation to the overall IC goal structures are also discussed.

Proposed Changes for the Goal Structure of “Ensure Appropriate Commitment as IC”

Proposed Change No.1

Respondent 1: *“Look for appropriate operational notes can be changed to ensure use of appropriate operational notes by the IC. But I think why you want to look at them as an IC is to ensure that you want to familiarize with the risks and hazards related to that specific incident..... and also to update your knowledge how to overcome them.....”*

“ I think this is also true for the next goal.....mmmm... actually why we look for local knowledge as an IC is to make sure we are familiarize to such local knowledge...”

Respondent 5: *“As I said in SC rather than Look for appropriate operational notes, actually the objective is to ensure knowledge of possible risks and hazards and incident specific operational strategy... you better consider adding these”*

Goal Interviewee 2: *“operational notes are actually for better understanding of hazards”*

Goal Interviewee 4: *“Look for operational notes... is it a goal or a task...?...and also the next one...Look for local knowledge.....”*

The above comments from respondents and the goal interviewees suggest the importance of referring to operational notes. Yet they quite rightly identified it to be a task rather than an objective. The actual goal behind this activity is to make sure IC become familiar with the specific risks and hazards relevant to that particular incident, and to identify the specific

strategies suitable for it. Therefore, this particular sub-goal of “*Look for Operational Notes*” was appropriately changed to two sub goals “*Ensure Familiarization on appropriate Incident Specific Operational Strategies (Pre-Planned)*” and “*Ensure Familiarization on Incident Specific Risks and Hazards.*” At present, every FRS of the UK has developed site specific Operational Risk Reviews (ORRs) known for all the high-risk built environments belonging to the boundaries of their county. These documents primarily define the risks and hazards unique to that particular incident. Also, these documents describe some pre-planned operational strategies to overcome the site specific risks and hazards. For the similar reasons expressed, the sub-goal “*Look for accurate incident specific local knowledge*” is also changed to “*Ensure Familiarization on the Incident Specific Local Knowledge.*”

Proposed Change No.2

Respondent 5: “*What you meant by receipt of knowhow on deployed controls and measures are the overall strategy deployed for operations and resources.....isn't it.*”
Otherwise, make sure it includes the knowhow of both tactics and resources...”

Respondent 2: “*As IC why I want to know the controls and measures is purely because I want to familiarize with the operational strategies already deployed at the incident. Operational strategies are usually two folds. One would be strategies related to the resource and asset deployment and requests. Other would be to familiarize with actual operational tactics or strategies of your major operations such as fire fighting, rescue or salvage.*”

Goal Interviewee 1: “*Must ensure knowhow of overall operations. It mustn't limited to only to operational tactics.*”

Goal Interviewee 2: “*What about knowledge on resources and assets?*”

These comments were made in relation to the goal of “*Deployed Controls and Measures.*” Revisiting the initial interviews revealed that ICs are worried about gaining knowledge on the resources and operational strategies deployed by previous ICs at their commitment. Therefore, the goal “*Ensure Receipt of Knowhow on Deployed Controls and Measure*” was changed to “*Ensure familiarization on ongoing Operations.*” Further, two more goals, namely, “*Ensure familiarization on planned and deployed strategies for Fire Fighting/Search & Rescue/Evacuation*” and “*Ensure familiarization on Deployed and Expected Resources & Assets*” were added as two sub goals to this revised goal.

Proposed Change No.3

Respondent 1: *“Meaningful on arrival self observation. This is very important.... Americans tell this as size up... we called it 360 degree. So it is better to change the wording.”*

Respondent 2: *“Meaningful on arrival self observation is usually called as 360 degree observation. But rather than a goal, isn't it a task to ensure accurate information?”*

Respondent 3: *“Meaningful on arrival self observation normally called as 360 degree.”*

Respondent 5: *“I think self observation is more of a physical task you do rather than an objective or a target...”*

Goal Interviewee 1: *“self observation, is this 360???”*

Goal Interviewee 4: *“360 is more appropriate.”*

The repeated comments made above by the SMEs suggest that *“Meaningful on arrival self-observation”* is equivalent to the common fire and rescue practice of *“360 Degree Observation.”* However, it was decided to remove that particular sub goal from the structure as it represents the characteristics of a task that is carried out by the ICs to ensure capturing all other various forms of information rather than a goal.

Proposed Change No.4

Respondent 1: *“You need to reword ensure receipt of incident knowhow as ensure receipt of information on the incident. Anyhow, I feel you repeat this by including meaningful on the way and on arrival input of incident knowledge. I think it you have duplicated the same goal.....”* *“...meaningful on the way and on-arrival input of incident related knowledge should be changed to incident information on-route and on-arrival.”*

Respondent 3: *“Actually in the goal of meaningful on the way and on-arrival input of incident related knowledge, the wording on the way should be changed as on-route.....it is more appropriate.”*

Respondent 4: *“Personally for me Ensure receipt of incident knowhow and its sub-goal Meaningful on the way incident related knowledge gives the same meaning. So why not consider removing one of them.....”*

Respondent 5: *“I feel meaningful on the way and on-arrival input of incident related knowledge must exclusively represent the site specific information.....”*

The above comments suggest that *“Ensure Receipt of Incident Knowhow”* is very similar to one of its subsequent goals; *“Meaningful On-the-way and On-arrival Input of Incident-Related Knowledge.”* Therefore, to avoid duplication of goals, *“Ensure Receipt of Incident*

Knowhow” was removed from the goal structure. It was replaced by the “*Ensure On the way and On-arrival Familiarization on Incident-Related Knowledge.*” However, considering the comments made by Respondents 1, 3 and 5, this particular goal was again changed to “*Ensure On-Route and On-Arrival Familiarization on (site specific) Incident Related Knowledge*”

Proposed Change No. 5

Respondent 3: “*What happened if you are the first person to commit as IC, then there will not be any operations to be assess or monitor isn’t it. So I think in that sort of commitment rather than assessing what has already implemented as an IC you may have to carry out an initial risk benefit analysis before, and then should start the initial planning of strategies for all the operations. Therefore, I think it is important to mention this in the box of progress assessment and give some prominence to first IC commitment.....*”

Although it was mentioned by a single interviewee, Respondent 3 here highlights a possible important difference between the first IC and the ICs to follow. Respondent explained the importance of recognizing the commitment of an IC who arrives with the first fire engine and therefore, automatically takes up the job as the initial IC. Having considered this, the original goal “*Ensure Accurate Assessment of Operational Progress*” was changed to “*Ensure Accurate Assessment of Operational Progress (In the case of first IC to attend - Ensure on-arrival risk benefit analysis).*”

Proposed Change No. 6

Respondent 3: “*I’m bit confused with the term commitment. It is actually the takeover from somebody else isn’t it?*”

Respondent 4: “*It is better if you consider changing the wording of your heading....mmmm... I think takeover would be easier to understand*”

Based on the above suggestions, it was decided to incorporate the term “*takeover*” into the goal title and change it to “*Ensure Appropriate Takeover / Commitment as IC*” to improve the clarity of its interpretation.

Remark 1

Respondent 1: “*Proper takeover is an important responsibility of a senior IC. So it is important to have an exclusive goal for it.....*”

Respondent 4: “*You are spot-on on this*”

Respondent 4: *“This is very important as we teach to do this by using correct terminology with the use of mnemonics”*

Above comments, indicated the importance of identifying appropriate commitment of an IC as a top-level goal of the IC goal hierarchy

Remark 2

Respondent 5: *“You’ll have to maintain consistency in terms like coordination and ensure. It would be better to interpret everything as Maintain appropriate incident wide fire-fighting /evacuation/search and rescueI guess it would bring consistency to your diagrams”*

The above feedback highlighted the importance of maintaining the consistency of terminology throughout the goal hierarchy. Thus, apart from above major changes several minor changes were carried out to make the terminology of the goal hierarchy more consistent and meaningful.

General Feedback Received on Interpretation of Terminology

Apart from the proposed amendments, all the participants commented on the use of terminology. Most of them indicated frequent mismatches in the use of terminology of the goal structures compared to the terminology used in the FRSs.

Respondent 1: *“Only concern is its terminology; terminology is different and have more academic look than the usual operational look we have in the FRS.....”*

Respondent 2: *“Main concern is you are talking in academic terms we are talking in fire fighting terms therefore it would be useful when you talk to fire fighters next time to talk with fire fighting terms to get your information. Of course we are not the brightest people so better to translate your terms with our terms when you do your interviews.....”*

Respondent 3: *“It is lot clearer..... it is only terminology changes now.....”*

Goal Interviewee 1: *“Some terms do not match with the service terminology”*

These comments indicated that some of the terminologies used do not match the terminology actually used in FRS. Although this mismatch was evident at this stage, it was decided not to make a major change in the terminology as the audience of this work could come from other domains. These findings are intended partly to be used by other researchers of the project “SAFETYNET” in the form of a requirement analysis to develop an IS. Therefore, it was decided to maintain simple and generic terminology so that the outcomes would be easily understood by a wider audience.

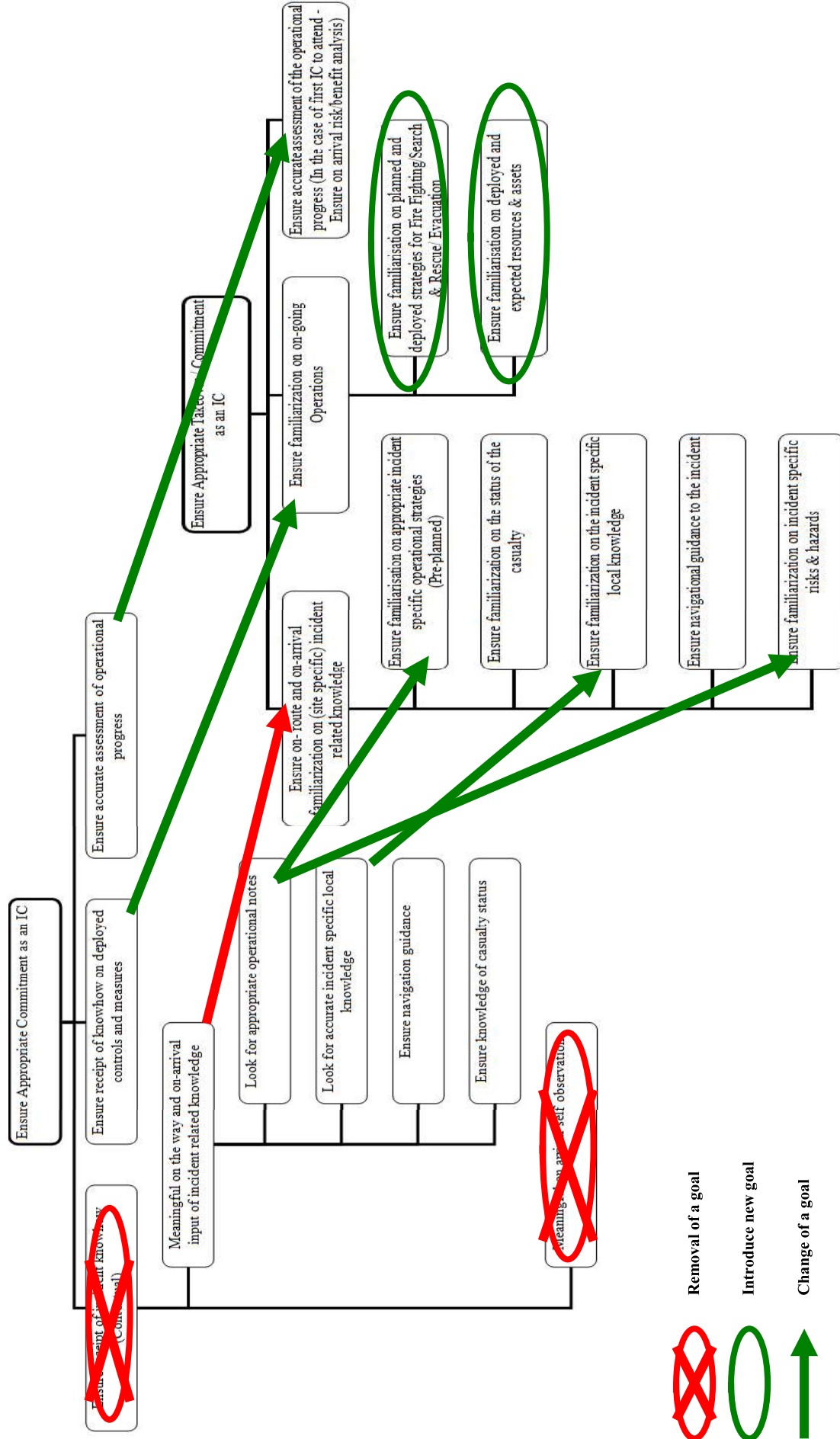


Figure 4.14: Amendments made to the Sub-goal Structure of the Secondary

Goal “Ensure Appropriate Commitment as IC”

Having considered the above proposed changes initial goal hierarchy of the secondary goal “Ensure Appropriate Commitment as IC” was revised to form a modified hierarchy as shown in Figure 4.14. Similar to this example, validated versions of the goal hierarchy for all the remaining goals of all four job roles were obtained. The Figures 4.15- 4.28 show the validated top level goals of the three of remaining firefighter jobs.

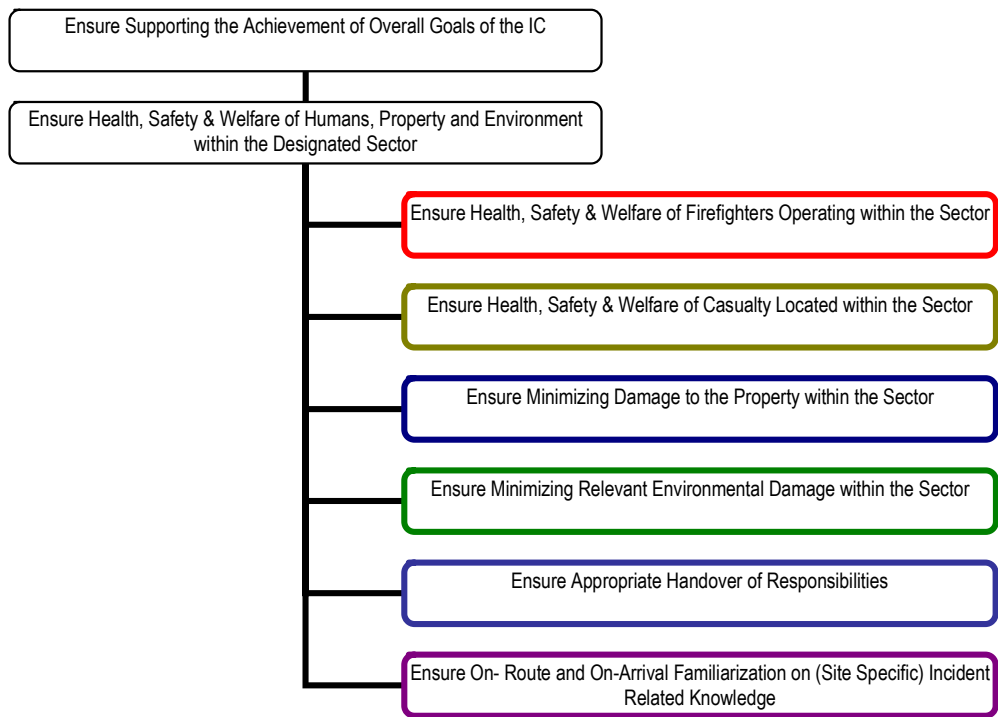


Figure 4.15: Validated Primary and Secondary Goals of a Sector Commander

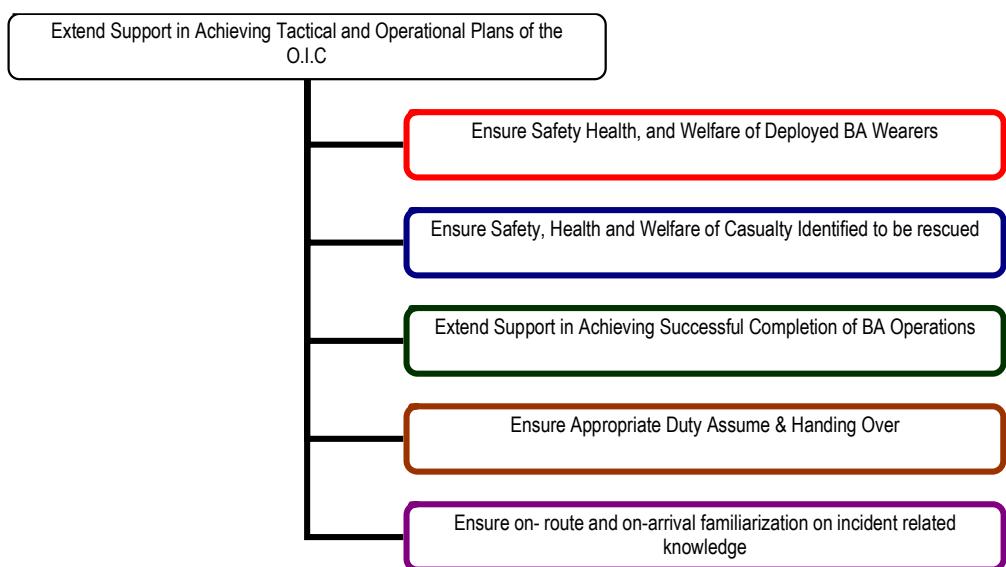


Figure 4.16: Validated Primary and Secondary Goals of a BA Entry Control Officer

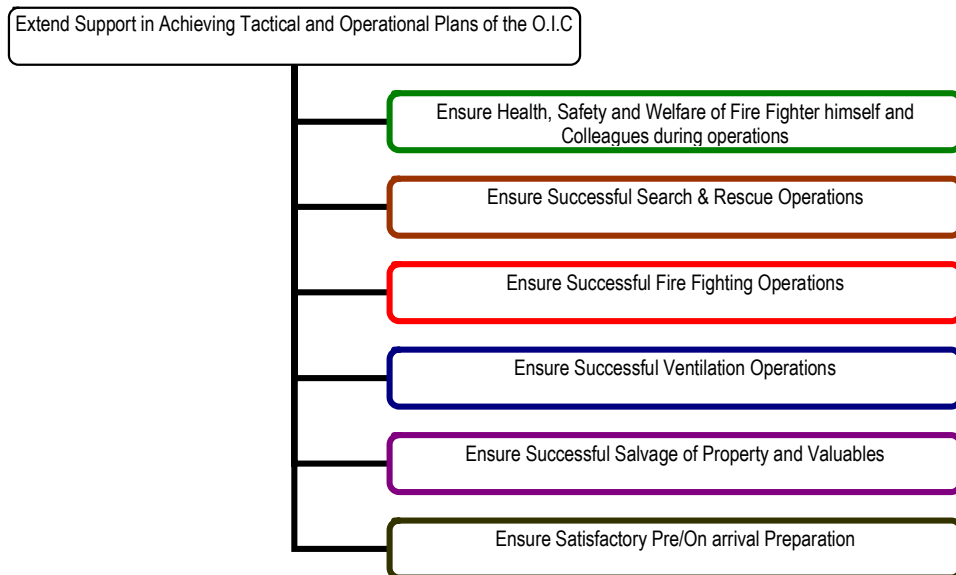


Figure 4.17: Validated Primary and Secondary Goals of a BA Wearer

In addition, validated goal hierarchies of several selected secondary goals relevant for each job role are attached in the Appendix 4.10.

4.7.2 Remarks with Regard to the Overall Validity

Remarks made in relation to the overall validity of the developed goals structured were identified when observing some of the other comments made under specific topics as well as under the topic of *general comments* captured in the transcription templates of the IC.

Some of the expressions repeatedly described by many participants in relation to the overall validity of the developed goal structure of the IC are illustrated in the following:

Respondent 1: *“What you have developed more or less represents the objectives of IC”*

Respondent 2: *“I have not seen something like this, which has been put down what we are doing, it is quite impressive and comprehensive. What you have put down for my eyes is correct....”*

Respondent 3: *“What you have got here almost covered all the objectives. You are almost getting there isn’t it?.....”*

Goal Interviewee 1: *“Good work...”*

Goal Interviewee 2: *“Apart from minor comments you have done a complete job”*

General feedback such as the above justified the developed goal structure as a suitable representation of the goals to be achieved by an IC during a large-scale fire emergency.

The acceptance or satisfaction of the SMEs with the goal structures developed was not limited to the job role of the IC. The transcription extracts captured for other job roles show a similar level of acceptance as illustrated in the following quotes.

General Feedback for the SC Goal Structures

Respondent 1: “.....I think you have captured comprehensive objectives and seemed to cover almost all the things of a SC””

Respondent 2: “..... It is really comprehensive and holistic.....”

Respondent 4: “..... As illustrated in the goal structures all the objectives of SCs are focusing towards achieving overall objectives of the IC.....”

General Feedback for the BAECO Goal Structures

Respondent 2: “.. As mentioned, most things you have got is spot on. I’m impressed how you have managed to take some of the things what we have discussed during the course in to your findings. Actually this would be quite useful for us as well...”

Respondent 3: “...Overall it is pretty good... I can’t see any major short coming.....”

General Feedback for the Fire Fighter Goal Structures

Respondent 1: “...I think really to some degree what you have done has highlighted what we are currently doing here at the school at higher level..... It is good work.....”

Respondent 2: “Yes ... it is pretty good.... You have covered almost all the things handled by a wearer in a major fire rather than a small house fire..... Can’t think anything more to it””

Respondent 3: “What you have got here is most appropriate.....”

Therefore, after incorporating the changes proposed the amended goal structures are taken to represent the generic goals of the four job roles investigated.

4.8 Elicitation of Decision-making and Information Requirements and the Development of Goal-Decision-Information Diagrams

The Decision-making Requirements and Information Requirements were also captured by having face-to-face interviews with selected firefighters. Having considered the large number of items to be discussed for a single job role and due to the limitation in the

availability of SMEs for interviews, the number of participants selected for each job role was increased compared to the previous data gathering phases. Five officers, representing each of the four job roles were interviewed. Participants for each job role were selected carefully to represent both experienced and novice experts. This particular set of interviews was carried out with the SMEs selected from the fire stations in the county of Derbyshire. During the selection process, efforts were made to provide equal opportunity for both experienced and novice firefighters. Furthermore, as in the exercise of goal elicitation, to avoid any interior biases within the county, officers were selected from fire stations located in various parts of the county. Such selection of fire stations allowed interviewing both full-time and retained firefighters. Efforts were made to select the SMEs who had already participated in the previous phases of the data-capturing as a means of reducing time to introduce the initial explanation of scenarios and therefore, allowing much longer time for the actual elicitation of information and decision-making requirements. Based on above criteria, experienced and novice firefighters representing both urban and rural fire stations were selected as shown in Appendix 4.11.

As described in the steps of the GDIA, these interviews were essentially focused on identifying the decision and information requirements that support the SMEs during their response operations in relation to managing the types of fires described in the scenarios. Therefore, an interview guide consisting of open-ended questions and prompts capable of maintaining the focus and motivation of the interviewees was developed. As illustrated in Appendix 4.12, this interview guide essentially consists of four types of probing elements:

- Four fire scenarios as the primary planned interview probes.
- Open-ended questions developed with the use of goals and sub goals being identified during the 3rd phase of the GDIA. These act as predefined grand tour questions on which interviewees were requested to describe their requirements for decision-making followed by the corresponding information requirements.
- Use of a Higher-level goal as a planned secondary discussion prompt to obtain more specific and elaborative information and decision requirements relevant to the sub goal/s of that particular higher-level goal.
- Simple, floating prompts and guides to facilitate continuous and meaningful discussion.

The above considerations introduced some control to the interview sessions. Therefore, the outcomes of the interviews are expected to become much more accurate and complete compared to unstructured interviews.

Before commencing, a brief introduction was given to each participant in relation to the expectations of this particular interview. If participants had not participated in the previous interview sessions, they were motivated by explaining how they could benefit from the outcome of this study. Thereafter all the participants who were new to the process of GDIA and therefore, facing their first GDIA interview session were introduced to the four fire scenarios. Arrangements were made to send the developed interview scenario documentation to all the new participants as a measure of saving valuable interview time. Such arrangement gave an opportunity for the new interviewees to become familiar with the scenarios prior to the actual interview session. On the other hand, SMEs who had already participated during the goal elicitation exercise were only taken through a brief refresh session on the scenarios. Later, SMEs were asked to describe the decisions they have to make to achieve their expected goals successfully with the aid of the prepared interview guide. With the use of decision-making related statements expressed by the participants, they were further probed to spell out their information needs to achieve better decision-making.

As described in Section 3.6.7, Step 6 of the GDIA procedure, during the elicitation of decision-making requirements, it was observed that participants found it challenging to express the actual decisions explicitly. They often took longer time to express the actual decisions related to goals. However, they found it much easier to express decision related problems and issues that they should address and questions they should answer in relation to underline decisions of a particular goal. Also, they took more time to describe decision related information requirements when they were probed with the actual decision. In contrast, participants found it easier to express the information requirements with the use of the interview probes describing problems, questions and issues related to the underline decisions. The following comments of several participants justify the above observation.

Interviewee 1 (IC Job Role): *“.... you see it is not easy to think what are the exact decisions....I will need much time to exactly tell you the decisions...yes...I think it is much easier to tell you problems or questions that I should solve inside my head for this particular goal....”*

Interviewee 11 (BAECO Job Role): *“.....Throughout this interview, most difficult for me is to imagine the actual decisions we make to achieve the goals....but I think the questions and problems we try to answer should have given you what exactly we are up to.....”*

Interviewee 1 (IC Job Role): “..Can I interrupt a bit... I find it rather easier to visualize information requirements from the problems and issues related to a decision rather than the decision itself....so it is better if we can stick to them in the next bit.....”

Again all the interviews were tape recorded and later analyzed by transcribing them to extract any possible decision-making and information requirement-related statement fragments described by each participant. Due to a higher number of open-ended questions, almost all the interview sessions were extended beyond the scheduled time although it was planned to finish them within 1.5hrs. Several interviewees agreed to face a second interview session for further clarifications. Due to emergency work commitments, several interviews were interrupted and continued at a later time.

Decision-making and information requirement related extracts were also captured. This was done by checking the observational field notes catalogued for various observations, referring to the UK Fire and Rescue Policy documentation, the ORRs and standard operating procedure documentation of the FRSs selected for the study. Such extracts were also tabulated in parallel with the findings of the interviews.

4.8.1 Data Categorisation

As described earlier, the intention of this particular phase of GDIA is to identify both decision-making and information requirements of SMEs in reaching their expected goals during a large-scale fire. Therefore, unlike the other two phases of the GDIA process, the classification of captured data was a rather simple exercise. Following Dey (1993), captured statement fragments, extracts from relevant documentation and observations were classified into two categories, namely:

- Decision-making requirements
- Information requirements

The goals and sub goals used as the secondary interview probes were identified as the themes for further classification of the statement fragments. This was considered essential since this particular phase of the study intends to develop the GDI structure for each and every goal and sub-goal for a selected job role. Therefore, for each job role the final classification of statement fragments was based as illustrated in Figure 4.18.

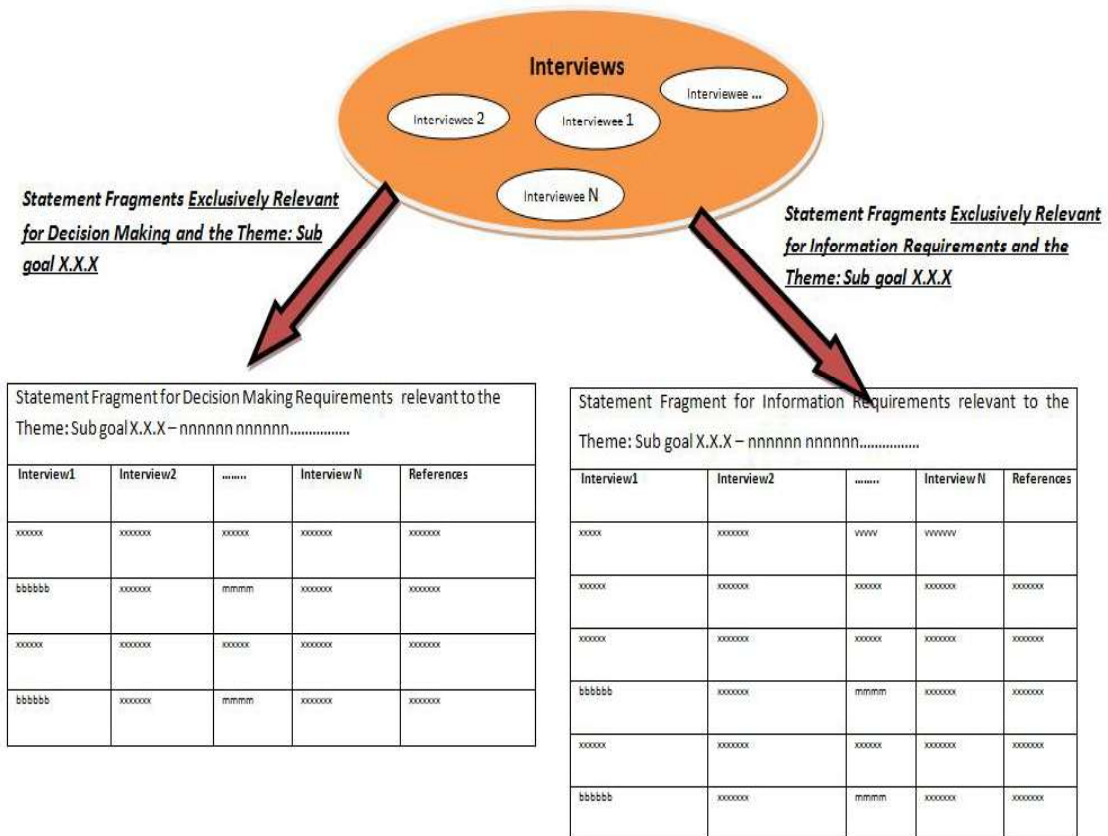


Figure 4.18: Classification of Statement Fragment into Decision-making and Information Requirements

4.8.2 Analysis for Elicitation of Decision-making, Information Requirements and the Development of GDI Diagrams

The transcriptions of each interviewee were examined to identify relevant fragments. These specific statement fragments were filtered against each theme (goal) that represents the decision-making and information requirements leading to a specific goal. The constant comparison method (Boeije, 2002) was used as the analysis tool. At the beginning, for each theme (goal), transcript extractions of the most experienced SME were examined. Thereafter, interview transcriptions of remaining participants were examined to capture the statements similar to the interpretation of fragments captured in the previous step. These fragments of each interview were tabulated parallel in two separate tables, one for Decision Requirements and one for Information Requirements. Subsequently, the transcript extractions were further examined for any additional fragments missed in the first round of comparison. The written documentation and observational field notes were also examined to elicit extracts containing the same or similar meaning. Such extracts were entered into the same table. This constant comparison technique was repeated for all the goals and sub goals identified for a particular job role and subsequently expanded to remaining job roles.

Finally, the interpretations of information requirements and the decision requirements were mapped to form the “GDI Diagrams” representing the goal, decision and information hierarchies of the each investigated job role. The information requirements were further classified according to the three increasing levels of SA: Level 1: Perception, Level 2: Comprehension and Level 3: Projection as described by Endsley (1995).

4.8.3 Elicitation of the GDI Diagrams of an IC

It is a lengthy exercise to illustrate the above analysis process undertaken to develop the GDI diagrams for the four different fire and rescue job roles. Therefore, it was decided to select a specific part of the goal structure belonging to the job role of IC to highlight the flavour of the analysis process. In the previous phase of the study, the secondary goal “*Ensure Appropriate Commitment as an IC*” was selected at random to illustrate the development of its sub goals. Thus, to maintain continuity and consistency, it was decided to select the same secondary goal to illustrate the detail of the tabulation of statement fragments and document extracts. Furthermore, the same example is used to illustrate the development process of GDI diagrams.

Each sub goal shown in the revised goal structure (Appendix 4.10) of “*Ensure Appropriate Commitment as an IC*” was considered as suitable to develop either a specific open-ended question or a secondary interview prompt to capture the decision and information requirements. When referring to the revised goal structure, the following sub goals of this particular secondary goal were selected.

- 3.1.1 Ensure familiarization on appropriate incident specific operational strategies (Pre-Planned)
- 3.1.2 Ensure familiarization on the status of the casualty
- 3.1.3 Ensure familiarization on the incident specific local knowledge
- 3.1.4 Ensure navigational guidance to the incident
- 3.1.5 Ensure familiarization on incident specific risks & hazards
- 3.2.1 Ensure familiarization on planned and deployed strategies for Fire Fighting/Search & Rescue/ Evacuation
- 3.2.2 Ensure familiarization on deployed and expected resources & assets
- 3.3 Ensure accurate assessment of the operational progress (In the case of first IC to attend – Ensure on arrival risk/benefit analysis)

To explain the detail analysis of carried out in the process of developing GDI diagrams for the above goals, sub goal 3.1.2 “*Ensure Familiarization on the Status of the Casualty*” is considered. The Appendix 4.13 contains a complete list of Decision and Information Statement fragments captured and the corresponding Decision and Information requirements interpretations related to this particular tertiary goal. Corresponding to these interpretations the Figure 4.19 corresponds to the mapping of those decision and information interpretations to form the GDI diagram of the sub-goal “*Ensure Familiarization on the Status of the Casualty.*”

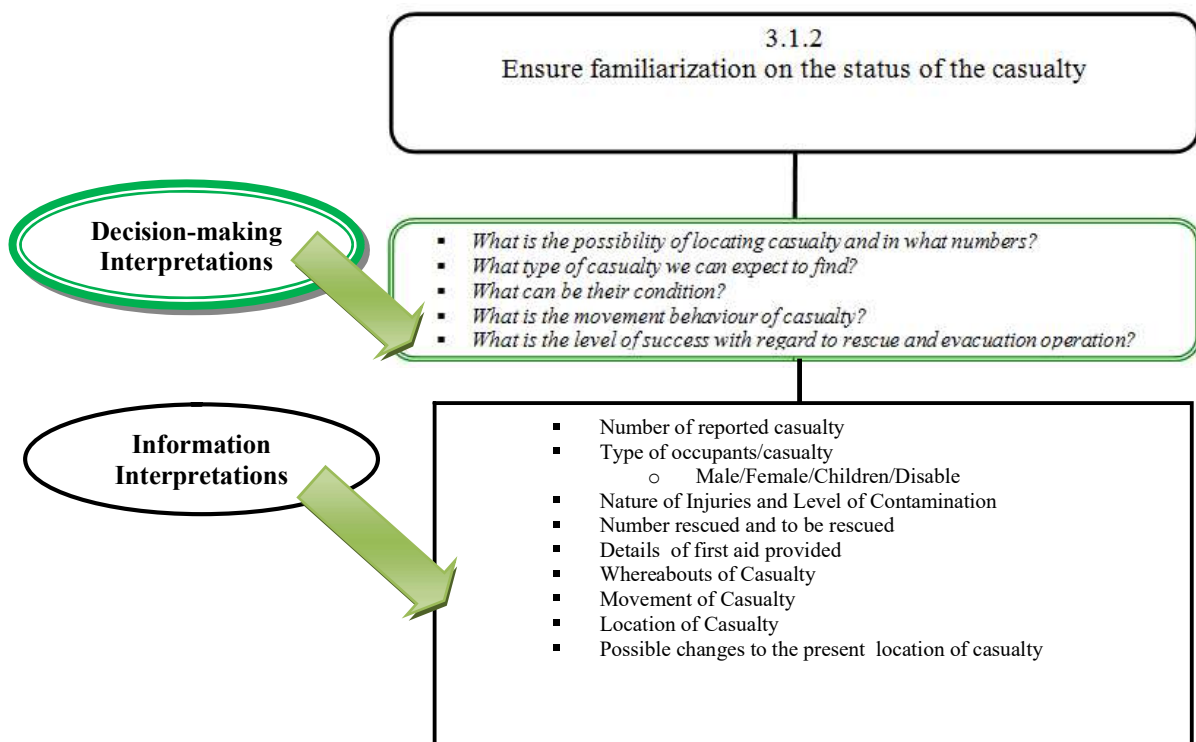


Figure 4.19: Illustration on Mapping of Decision-making and Information Requirements to form a GDI Diagram

For this particular sub goal, decision-making requirements captured were in the form of questions related to the underling decisions rather than the decisions itself. However, they were quite effective as probes to obtain the comprehensive information needs corresponding to the goal. Following Endsley (1995), these information requirements belonging to the GDIA diagram were further classified into three increasing levels of SA (Yang et al., 2009b; 2009c). This classification was based purely on the perception of the researcher of the information elements in the context of a fire ER. These perceptions were

formed by the extensive observation of fire training exercises and scenarios throughout the fieldwork period of this study. The following levels of SA were used:

Level 1- *Perception*: According to the researcher's judgement, this is a piece of isolated information capable of conveying the status, attributes and dynamics of a relevant element in the environment. Or

Level 2- *Comprehension*: According to the researcher's judgement, this is information capable of building a holistic picture, which is considered to be the synthesis of several disjointed Level 1 information components. Or

Level 3- *Projection*: According to the researcher's judgement, this is information capable of projecting the future actions of an element in the environment, which may need both Level 2 and Level 1 components together.

The following components were perceived as only capable of conveying the status, attributes and dynamics of a particular element within the environment of a fire incident and were categorized Level 1 SA requirements.

- Number of reported casualties (attribute/status).
- Type of occupants/casualties (attribute)
 - Male/Female/Children/Disabled.
- Nature of injuries and Level of Contamination (attribute/status).
- Number rescued and to be rescued (attribute/status).
- Details of first aid provided (status/attribute/dynamics).
- Whereabouts of casualties (attribute/dynamics).

Furthermore, there were two other information components:

- Movement of casualty
- Location of casualty

These were perceived as being capable of building a holistic picture where both components need to incorporate location information in combination with thematic mapping information. Therefore, these two components were categorized as capable of delivering Level 2 SA requirements.

Finally, the remaining information component "*Possible changes to the present location of casualty*" was categorized as capable of delivering Level 3 SA since it requires a high-level

of prediction and consideration of the actions of the casualty in light of the expected changes to the conditions of the incident ground and the structure of the building. Having considered the above arguments final classification of information is graphically illustrated in Figure: 4.20.

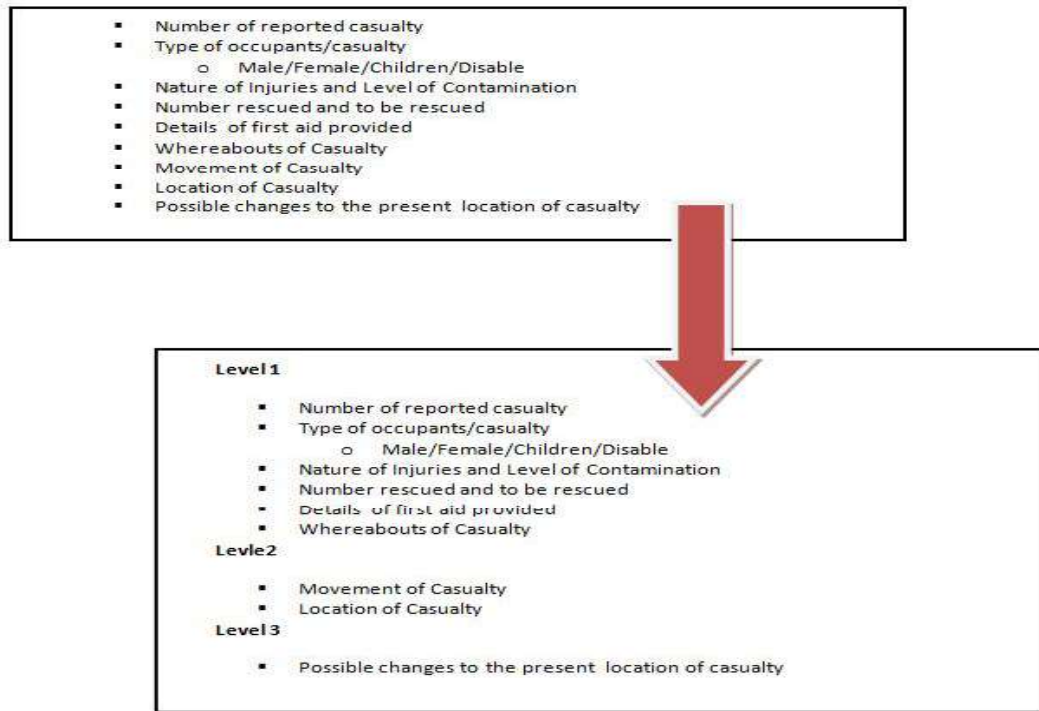


Figure 4.20: Classification of Information Requirements into 3 Tier Schema of SA

The above organization of information provides a useful structure for system design purposes (Endsley et al., 2003b). However, it should be mentioned that generally, several number of Level 1 and Level 2 items may be used to form Level 3 information (Endsley et al., 2003b). Furthermore, at times, Level 3: *Projection* information may also be used to assess the information representing Level 2 SA requirements (Endsley et al., 2003b). Sometimes definitive categorization of SA requirements into a single level is not possible (Endsley et al., 2003b). In such instances, item is placed in multiple levels in a manner that it reflects its meaning at each level.

A similar procedure was carried out to develop the GDI diagrams for the remaining sub goals of the secondary goal “*Ensure Appropriate Commitment as an IC.*” Similar to the above example, captured statement fragments related to these remaining goals were summarised and interpreted as shown in Appendix 4.14 to form the Decision-making Requirements and Information Requirements of an IC. These interpretations were later

transferred and mapped to form the corresponding GDI diagram related to each of the selected sub goals. Later, it was further extended to the rest of the secondary goals of the IC as well as for all the goals of the remaining job roles.

4.9 Validation of Goal - Decision - Information (GDI) Diagrams

It was considered important to discuss the GDI diagrams with relevant SMEs, and get their feedback since the objective of these diagrams is to identify the information needs relevant to a particular job role and it is important to validate the findings.

Validation started with the distribution of the GDI diagrams to all the participants of the GDIA interview sessions. This was carried out by having a brief face-to-face discussion with the respective SMEs and explaining how to interpret the diagrams. During these introductory sessions, SMEs were encouraged to provide useful comments on the diagrams by being shown a few examples and by being provided with a comment sheet (Appendix 4.15).

Parallel to the above exercise, the other set of SMEs who participated in the goal validation exercise were met again with the aim of validating the GDI diagrams. However, providing feedback for all the GDI diagrams is an impossible task for an individual participant, due to the amount of information to be verified for each set of GDI diagrams. Therefore, it was decided to select a random set of GDI diagrams relevant to one particular job role so that the number of selected diagrams could be comfortably discussed in a reasonable time. The duration of each brainstorming session was extended up to a maximum of 2.0hrs. During the sessions, SMEs were introduced to the selected set of GDI diagrams and were asked to state their comments and suggestions. During the interviews, these comments were transferred into the format described in Appendix 4.15 by the interviewer. Apart from taking down the comments, all the validation sessions were voice recorded. Later, the recorded voice files were checked to identify any missing or misinterpreted comments.

With the start of the “New Dimension” program (CLG, 2008c), Command Support teams across UK fire brigades are expected to play a significant role than before. Leicestershire and Derbyshire have recently invested in purchasing high-tech smart vehicles, which can accommodate the software to support the command support officers to better manage the

incident ground information. Currently, these teams are in the process of developing their own software with the aim of enhancing their information management capability. With this background, command support officers were considered a very good source of expertise for the validation of the GDI diagrams. Therefore, it was decided to get the feedback of the command support officers of both counties as an additional means of enhancing the outcome of this validation process. Presentations were carried out for the Command Support teams of the two counties and subsequently, they were requested to give their comments collectively.

The comments from the three different sources were summarised and interpreted to form a list of comments. Separate sets of proposed improvements were identified for the four job roles. Later, these suggestions were incorporated into the respective GDI diagrams to obtain the validated diagrams. With such rigorous feedback, these validated GDI diagrams are taken to represent the information requirements of the FRS brigades in the East Midlands Region accurately. There seems no reason to doubt they also present the requirements of other counties of the UK where FRS brigades are facing large-scale building fires.

The GDI diagram for the sub goal “*Maintain Strategy for/Coordination of Removal or Neutralization of Harmful Utilities/Equipment*” can be taken as an example to illustrate how the process of validation was carried out and how changes were introduced to the initial draft of GDI diagrams. This GDI diagram represents one of the tertiary goals belonging to the job role of an IC. This selection was made on the basis that this was one of the GDI diagrams, which received the highest number of comments from all three validation sources. By referring to the comments shown in the Appendix 4.16.1, 4.16.2 and 4.16.3, which received from the three different validation sources, changes were proposed to improve the viability of the original GDI diagram as shown in Figure 4.21.

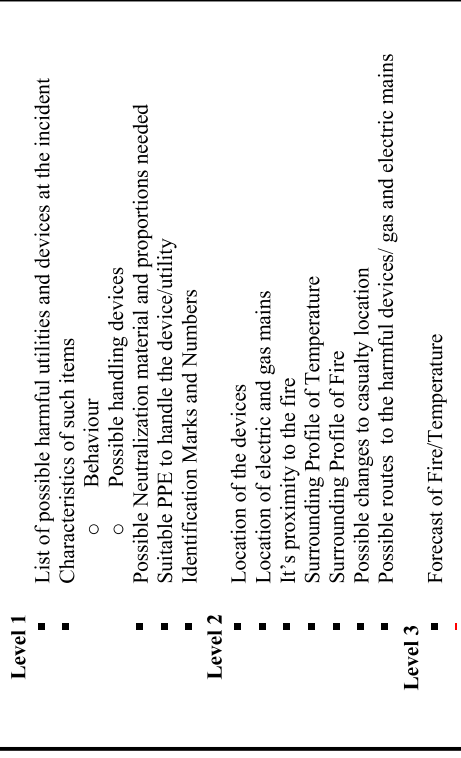
Similar to the above example, validated versions of the GDI diagrams for all four job roles were obtained. Altogether, 323 validated GDI diagram were developed for the four job roles with the breakdown of 88 Diagrams for the IC, 66 diagrams for the SC, 62 diagrams for the BAECO and 107 for the BA Wearer. A sample representing validated GDI diagrams obtained for each job role is attached in Appendix 4.17.

Before Validation

2.1.3

Maintain Strategy for / Coordination of Removal or Neutralization of Harmful Utilities/Equipment

- Are there any harmful devices/utilities at the incident and what can be the impact?
- If it is a domestic utility like gas and electricity, how can they be cut off?
- Can we handle the devices safely?
- How to reach such sources?
- Can we reach them safely?



After Validation

2.1.3

Maintain Strategy for/ Coordination of Removal or Neutralization of Harmful Utilities/Equipment

- Are there any harmful devices/utilities at the incident and what can be the impact?
- If it is a domestic utility like gas and electricity, how can they be cut off?
- Can we handle the devices safely?
- How to reach such sources?
- Can we reach them safely?
- What can be the impact on people/public/environment/building?
- Do we have required specialist support at the incident?
- Can we define the safe area suitable for the operations?

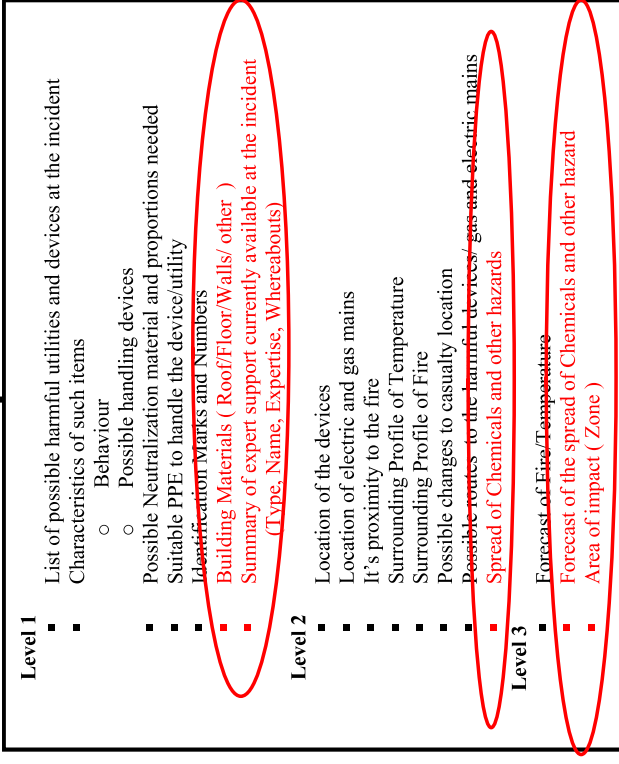


Figure 4.21: GDI Diagram for Goal “Maintain Strategy for/ Coordination of Removal or Neutralization of Harmful Utilities/Equipment” Before and After Validation

In addition to the comments to improve the validity of the initial GDI diagrams, participant's remarks on the overall validity of the developed GDI diagrams were also identified. A selection of some of the prominent expressions of both the interviewees and the validators repeatedly stated in relation to the overall validity of the developed GDI diagrams are illustrated below:

Respondent 1 (IC Job Role): *"I think you have managed to capture the most comprehensive set of requirements..... It is brilliant....Yes ... there are changes here and there.....but that is why you are doing this validation isn't it... So after considering these validation comments these diagrams will be almost perfect.....What you have developed more or less represents the objectives of IC....."*

Respondent 4 (SC Job Role): *"This is excellent stuff.. when you include the comments I made today and of course the comments of the others it can be further improved.... What I like it most is that you have put a really good foundation, which we couldn't do it for years...."*

Respondent 2 (BAECO Job Role): *"...You have done a wonderful job... the way you have managed to link the information requirements to the goals is excellent... I think the biggest secret is you have managed to capture some excellent set of decision probes ... when I go through them I can see you haven't missed anything....that is why I think you have managed to capture this much comprehensive set of information requirements....."*

O.I.C Leicestershire Command Support Team: *"....What you have identified is great..... can you please send me a copy of this after the modifications.... I really like to try this with our new system I think it is an ideal upgrade to our flash cards....."*

Interviewee 3 (IC Job Role): *"Excellent.... the best bit is you have managed to identify a comprehensive set of decision probesthat is why I think you have managed to identify the information needs like this..... I don't think anybody can say that you have missed anything....it's comprehensive because you first identified the goals.....so you don't miss many....."*

Interviewee 13 (BA Wearer): *"....You may need to do some modifications... but definitely it will be not much... already you have obtained an excellent set of requirements..most important for you is that your diagrams are comprehensive.....Even for me this is the first time I could really see the actual requirements we really like to haveso from here onwards it will not be difficult to make it perfect....."*

Many SMEs who participated for the validation sessions for all the four job roles described comments similar to the above. These comments clearly justify appropriateness, comprehensiveness and the accuracy of the developed GDI diagrams. The comments further confirm that after incorporating the changes proposed, the validity of the contents of the GDI diagrams could be further improved and therefore, could be more capable of representing the information requirements of the four job roles investigated.

4.10 Summary

This chapter has discussed and explained the primary data gathering and analysis of this study to elicit comprehensive information requirements of the firefighters responding to a fire emergency in a high-fire risk built environment. With the support of cognitive task analysis tool GDIA, information requirements in relation to the goals and decision-making needs of four core firefighter job roles were elicited in three increasing levels of SA and later validated. Compared to the previous studies this is the first known occasion where comprehensive information requirements of firefighters are identified and understood. Information requirements elicited become the basis for any ISs development in the FRS. The validation exercises showed a very positive response among a range of frontline firefighters indicating that this work has accurately and comprehensively identified the information needs of firefighters.

Chapter 5 : Development of the Human Computer Interface Mock-ups

5.1 Introduction

The aim of this chapter is to specify and develop software mock-ups that consist of human computer interfaces capable of enhancing the SA of four firefighter job roles. The chapter begins with a discussion of the interface design considerations. This discussion explains some design considerations related to the selection of appropriate design guidelines and principles for the human computer interface development process. It then explains several important contextual factors exclusive to fire Emergency Response (ER) that may influence the interface design. Next, the chapter discusses specific design decisions adopted in the process of designing the interfaces proposed. This discussion explains in detail how specific design decisions are applied for the context of fire ER by using some relevant examples. Finally, the chapter describes in some detail the features and functionality of the proposed interfaces by considering several example interfaces.

5.2 Design Considerations

It is decided to develop human computer interface mock-ups for four firefighter job roles with the aim of achieving the second objective of this study. Importantly the entire process of mock-up development is driven by the information needs identified in Chapter 4 for four different firefighter jobs. As explained in Section 3.8.3, at the beginning of the systems development process, it is vital to make appropriate design considerations related to the selection of suitable Design Principles and Guidelines and Contextual factors unique to fire ER that could influence the information systems design.

5.2.1 Design Principles and Guidelines

User interface design is a creative process (Shneiderman et al., 2009; Endsley et al, 2003b). Today a systems designer can come up with a great variety of design concepts with the amount of available Windows-based and Web-based technologies and hundreds of permutations of assignments of display and control requirements to those technologies (Shneiderman et al., 2009). Hence, there can be many viable ways to design the interfaces that will present the information required (Endsley et al, 2003b). Nonetheless, it is almost impossible to test all potential designs to discover their usability shortcomings. The only way to minimize the limitations of usability is through the application of an appropriate set

of user interface design principles and guidelines that allow designers to avoid many pitfalls in the design process (Shneiderman et al., 2009). Therefore, it is decided to identify and consider an appropriate set of interface design principles and guidelines suitable to develop human computer interface mock-ups for the use of different firefighter jobs.

Over the years, many guidelines and design principles have been developed (Shneiderman et al., 2009) based on scientific testing and empirical data collection. Guidelines and design principles establish how best to design system components to enhance human use (Endsley et al, 2003b). At the beginning, some useful contributions made by Boff et al. (1986a; 1986b), Eastman Kodak Company (1983), Sanders and McCormick (1993) and Woodson et al. (1992) came from the Human Factors and Ergonomics domains. However, later many guidelines centered on specialized topics exclusively related to Human Computer Interaction (HCI) emerged with the advancement of the mobile computing, web design, online communications, information visualization and virtual environments (Shneiderman, 1997). According to the Shneiderman (1997), the key topics addressed by various user interface design guidelines can be classified into 1) Navigating the interface, 2) Organizing the Display, 3) Getting the users attention and 4) Facilitating data entry. Most of the user interface design guidelines are capable of supporting the presentation of different types of visual, auditory, and tactile information to allow successful human perception of information (Endsley et al, 2003b). Thus, most of these traditional guidelines and principles for user interface design form a necessary foundation for SA (Endsley et al, 2003b). However, these guidelines do not go far enough to support high-level of SA under demanding circumstances (Endsley et al., 2003b). These guidelines and principles mostly support the component level design. SA, by its very nature, is highly affected not only by the design of individual system components but by how those components are integrated. Furthermore, these guidelines are primarily focused on the perceptual and physical attributes of humans but not on their cognitive attributes. To overcome the deficiencies, Endsley et al. (2003b) proposed an interface design guideline consisting of an additional set of principles to augment the previous traditional design guidelines. As described in Chapter 2, this guideline consists of 50 SA oriented interface design principles grouped into the following categories (Bolstad et al., 2006):

- General
- Confidence and Uncertainty
- Dealing with Complexity,

- Alarms, Diagnosis and SA,
- Automation and SA
- Supporting SA in Multi-Person Operation

This is the only known set of principles found in the literature, exclusively formulated, to guide the design and development of a system to enhance SA of its end-users. As explained in Chapter 2, eight principles in the “General” category are the primary principles of the guideline (Bolstad et al., 2006). These are 1) Organise information around goals, 2) Present Level 2 SA information directly (support comprehension), 3) Provide assistance for Level 3 SA projections, 4) Support global SA, 5) Support tradeoffs between goal-driven and data-driven processing, 6) Make critical cues for schema activation salient, 7) Take advantage of parallel processing and 8) Use information filtering carefully. The other 42 principles, which belong to the remaining five categories, are considered the complementary principles useful to support the 8 primary principles in the “General” category. It is evident that these 42 complementary SA oriented principles address most of the interfaces design issues considered in various other conventional principles and guidelines. Also, it is observed that design guidance recommended in some of these complementary principles is very much similar to the recommendations of some of the popular conventional interface design principles.

Having examined various interface design guidelines and principles with the aim of developing mock-ups that simulate the functionality of human computer interfaces capable of enhancing SA of four firefighter jobs, the 8 primary SA oriented design principles (Endsley et al., 2003b) belongs to its “General” category are considered the core interface design principles suitable for this study. In addition, several conventional and SA oriented interface design principles and guidelines are also considered to improve the interface navigation, the organization of display, getting the users attention and the data entry.

Regardless of the type of the principles and guidelines they are global in scope and subject to interpretation (Mejdal et al., 2001). None of them are complete enough to adopt directly for designing user interfaces that suit a specific domain (Shneiderman et al. 2009). Thus, the guidelines and principles during the design process need fine tuning and necessary adjustments and should be converted into more specific design decisions (Mejdal et al., 2001). A similar stance was taken by the Endsley et al. (2003b), specifically in relation to

the 50 principles defined in their SA oriented design guidelines. Therefore, it is decided to further fine-tune and refine the above considered design principles and guidelines in light of the unique contextual factors related to the fire emergency domain and the identified information needs of the firefighters. The refining process of guidelines and principles into specific design decisions is referred to as “tailoring” (Smith and Moiser, 1986). At the end, such tailor-made refinements should provide a robust and exclusive set of design decisions suitable to meet the physical, perceptual and cognitive attributes expected in the human computer interfaces supporting firefighters.

5.2.2 Contextual Factors

Importantly, the mock-up interfaces proposed in this study should be capable of demonstrating various simulated features and functionality expected from a fire ER Information System (IS). As explained in Chapter 3, it is identified as important to consider various contextual factors unique to fire emergency situation that could have an impact on the design of the human computer interfaces. The contextual considerations are essential as it may reveal the differences such as the 1) mode of access to the information, 2) type and size of the interface and 3) content and amount of information to be displayed for different job roles and different contextual conditions. Furthermore, contextual considerations support tailoring of useful design principles and guidelines to match the fire emergency domain. Such considerations will help to develop the mock-up interfaces in such away they simulate an actual system expected by firefighters. Therefore, influential contextual factors exclusively relevant to the fire emergencies are considered prior to the development of the mock-ups. This includes contextual factors related to environmental conditions, characteristics and behaviour of firefighters during their operations, and use of the technology. As explained in Chapter 3, these contextual factors were identified during the previous stages of the study by having observations of fire training and simulation sessions, discussions and interviews with various subject-matter experts and further by referring to fire emergency related literature.

Excessive Noise: Ambient noise levels at the incident ground are very high compared to the office environment. Observations made during firefighter simulation and training exercises clearly indicated the excessive incident ground noise generated due to the sirens and alarms of various types of vehicles and the evacuation alarms activated. This is further increased by the noise of the pumps in operation and the engines of the vehicles. The noise of blazing

fire and collapsing equipment and structures also contributes to high incident ground noise. Further, as explained in the *Catalogued Field Note Ref. 4.29 based on the Observations made during BA Wearer Training on 21st (Day 6) July 2008* (Appendix 5.1), noise levels can be severe in areas where the frontline operation is carried out. *Catalogued Field Note Ref. 4.14 based on the Observations made during BA Wearer Training on 15th July 2008 (Day 3)* (Appendix 5.1) further justifies the above consideration. As explained in this field note, during BA Wearer training, training instructors made loud artificial noises simulating the noise levels expected in the working environment so that hearing capability of trainee firefighters become significantly low when they are closer to the epicentre of the incident.

Poor Visibility: Smoke filled conditions during fire emergencies significantly prevent the visibility of the firefighters (Hassanain, 2009). The visibility close to a smouldering fire could be reduced to a few feet (Klaene and Sanders, 2007). Thus, BA Wearers may not be able to devote visual attention continuously due to thick smoke and darkness. Consequently, during an incident, firefighters can be compared to that of a visually impaired person (Renaudin et al., 2007). These arguments were strongly supported by the observations made during fire simulation and firefighter training sessions, since they clearly indicated that visual acuity of the officers who work much closer to the epicentre of the actual incident are significantly low. Specifically, the thermal image movie clip made during the observation of the BA Wearer Training on 21st (Day 6) July 2008 and *Catalogued Field Note Ref. 4.29 based on the Observations made during BA Wearer Training on 21st (Day 6) July 2008* (Appendix 5.1) clearly show that when frontline firefighters getting closer to the epicentre of the incident, prevailing environmental conditions bring virtual disability. Behaviours of the firefighters clearly indicate that lighting levels in the area where actual operations are being carried out is very low or zero. In these conditions, firefighters use their limited vision to observe the surrounding to locate casualties, identify risks and hazards. *Catalogued Field Note Ref. 4.15 based on the observations made during BA Wearer Training on 15th July 2008 (Day 3)* (Appendix 5.1) further justifies the above arguments. As explained in this field note, during firefighter training firefighters are blind folded. The purpose of such activity is to simulate the less visual acuity expected near the area of fire.

Rapid Pace of Fire Fighting Operations: Pace of fire fighting operations, workload and stress levels vary depending on the job role as well as on the progress of the incident. Often

the pace of the operation is rapid and unpredictable for frontline firefighters and can position in the order of IC < SC < BAECO < BA Wearer. When it comes to the specific job role of IC, their pace of operations and stress levels are maximum at the beginning of an incident and ease off when incident progresses. Nonetheless, always there can be unpredictable pace changes. In general, rapidity of operations and stress levels of SC are much closer to those of an IC.

Variable Scope of Fire Fighting Operations: It is observed that, usually the scope of the response operations is widest for an IC and narrowest for a BA Wearer who is involved in a specific operation. The scope of operations of SC is much more focus and narrower compared to that of an IC. Furthermore, operational scope of BAECO is usually narrower than a SC. However, these generic conditions could suddenly change due to extreme and unpredictable changes of the conditions. For example, according to the *Catalogued Field Note Ref. 4.23 based on the Observations made during BA Wearer Training on 21st (Day 6) July 2008*, it is evident that a SC does not require knowing the exact location of a particular firefighter. It was observed that SCs are often satisfied with the whereabouts of firefighter operation. However, these requirements suddenly changed when a firefighter did not manage to evacuate before the level of air pressure of the breathing apparatus reaches the minimum level of safety. In such a situation, SCs were very much keen to find out the exact location of that particular firefighter. Due to the unpredictable nature of the emergency, cognitive demand for information is also unpredictable and change abruptly.

Hazardous Working Environment: Working environments are often hazardous for all the job roles. Comparatively, susceptibility to temperature and chemicals are very high on the incident around. In general, observations made clearly indicate that they can be positioned in the order of IC < SC =< BAECO < BA Wearer.

Differences in Level of Mobility: During their respective operations frontline firefighters are often on the move, while the mobility of all other job roles is very much restricted. Since BAECO always have to focus on their BA Boards, they are the least mobile and have almost zero mobility. In contrast, ICs wander around their mobile command post to talk to their subordinates and colleagues. However, they stay more time at their command post to talk to command support officers, to go through the information boards and other records.

In comparison, mobility of a SC is higher than an IC. However, their level of mobility may vary depending on the type and the location of the sectors.

Navigational Restrictions: Firefighter's navigation faces severe constraints due to safety and environmental difficulties. BA Wearers carry out their movements based on either *left hand* or *right hand* search by using the walls of the building as their main reference for navigation. This was observed during many firefighters' training sessions (Catalogued Field Note Ref. 4.19 based on the Observations made during BA Wearer Training on 17^h (Day 3) July 2008; Appendix 5.1). Moreover, a similar policy for fire fighter navigation is defined in the search and rescue procedure documents (Technical Bulletin 1/1997, 1997) as an established search and rescue procedure. However, at the beginning firefighters have to layout the physical ropes called "Guidelines" when they carry out operations in open areas such as warehouses, where boundary walls are far away. Later, these guidelines are used as the main navigational aid (Technical Bulletin 1/1997, 1997). Apart from the above, fire fighting teams use a "Personal Line" to maintain a physical link between a firefighter and the navigational "Guidelines" and two fire fighters (Catalogued Field Note Ref. 1.7 based on the Observations made during the Fire Simulation Exercise at Rolls Royce Nuclear, Derbyshire on 13th July 2007; Appendix 5.1). In some occasions, firefighters use the service of their water hose as a navigational aid. Although these tools increase the safety of firefighters, they drastically restrict the physical movement. Firefighters often face difficulties using the guidelines and their water hose as a means of navigational guidance as these can be easily tangled with equipment and furniture located inside the buildings (Catalogued Field Note Ref. 4.19 based on the Observations made during BA Wearer Training on 17^h (Day 3) July 2008; Appendix 5.1). When evacuating with a casualty, it is increasingly difficult for firefighters to use the support of either a guideline or their water hose as an evacuation support. In addition, there is evidence of firefighter deaths due to entangled guidelines (Denef et al, 2009).

Less Physical Freedom for BA Wearers due to PPE: All the firefighters should wear designated Personnel Protective Equipment (PPE) required for the particular job role. Due to an excessive number of PPE, BA Wearers have the least physical freedom compared to any other job role. With thick gloves on, it is very difficult for a frontline firefighter to use hands to control a device, which need precision touch. Furthermore, firefighters always use their hands to carry and operate firefighting equipment such as water hose, to inspect the

surrounding, to find their way and to avoid hazards and obstructions. Therefore, compared to any other job role, use of hands for the control of devices could become infeasible for frontline firefighters. *Catalogued Field Note Ref. 4.8, 4.15, 4.25 based on the Observations made during BA Wearer Training on 16th (Day 2), 17th (Day 3) and 21st (Day 6) July 2008* justify the above consideration (Appendix 5.1).

Additional Workload for ICs due to Post Incident Considerations: It was observed that currently during a large incident, ICs are assigned several responsibilities of capturing, saving and carrying forward the information related to what happened at the incident. Recording and logging critical information that needs to be retained is one of those responsibilities. This includes a written log maintained in the *Command Unit* during the incident or voice recording of critical messages. Furthermore, the IC on an incident ground often assigns appropriate officers to maintain records of the *Analytical Risk Assessments*. Every IC has to devote time and effort during the emergency to make arrangements to retain some crucial information for the future benefit. As explained below, some of the interviewees during the GDIA process explained how added workload due to post incident consideration caused ICs to sacrifice their valuable time and effort, which would be more beneficial in dealing with other ongoing response operations. In addition, this added workload may affect their attention to detail related to some crucial aspects during the ER operations.

Interviewee 2 (Goal Capturing Interviews): *As I mentioned post incident considerations are very important for us..... But frankly as the IC I should not put a lot of effort on thatit can take a lot of time and effort of my capacity that should ideally focus on actual fire fighting... Sometimes we might miss some crucial ongoing issues as we have to put a lot of effort to coordinate post incident considerations.....*

Interviewee 4 (Information and Decision Capturing Interviews): *It is true that post incident considerations is one of our primary goals.....but I feel all that effort is unnecessary...yes you need some involvement as an IC.... but it is too much now with our current practices.... If the system can somehow collect and maintain all the necessary information useful for this particular goal, we can save our energy to do our IC job much better.....simply we could save more lives and property.....you see, the day by day we are asked to fill more forms.....*

Hearing and Visual Disabilities: Usually in the UK, hearing and visual disabilities are considered as disqualification to work in the Fire and Rescue Service (FRS). However, currently this applies only as a health hazard in relation to carrying out the physical operations. The FRS brigades of the UK adopt different policies across different counties during the recruitment of firefighters who are colour blind. Since 10% of males and 1% of females of the general public are suffering from some form of colour blindness, there is a possibility that some of the firefighters are colour blind (Few, 2006).

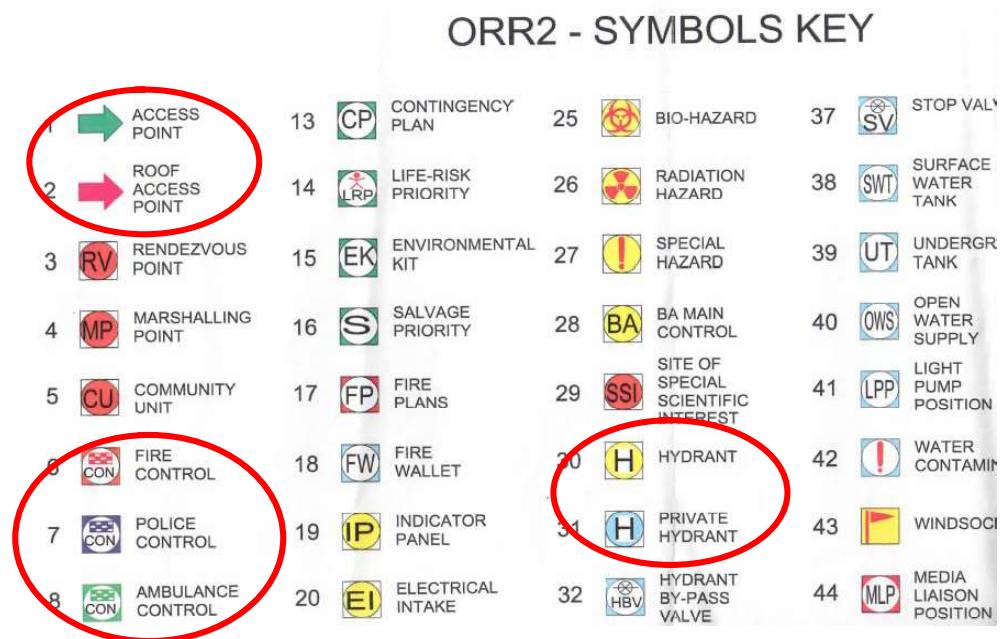


Figure 5.1: An Extract of Category 2 Operational Risk Review Symbol Keys of Derbyshire FRS

But as a percentage, amount of colour blind firefighters is far below the average compared to the general public. Although there are few firefighters with some form of colour blindness, FRS documentation revealed that they use colours to a greater extent and consider colour as one of the main mode of visual information (DFRS, 2009). In fact, there is evidence that colour is solely used to deliver a meaning. As shown in Figure 5.1, some of the symbols in operational risk reviews related to the high-risk fire sites belong to the Derbyshire FRS (DFRS) use colours exclusively to demarcate types of hydrants, various incident locations and different types of access. However, few of these visual implications are currently considered in relation to the use of IS displays.

Differences of Skill Levels: At any given moment, during a fire ER operation, there is a possibility a particular job role of the incident command hierarchy that consists of firefighters with different levels of skill and experience. A frequent observation during simulated fire ER training events indicates that skill levels of firefighters vary considerably depending on their experience. The number of similar incidents faced and the time since the last operation similar to the current operation are more significant factors for enhancing skill levels than the number of years in the service. Furthermore, the skill levels of full-time firefighter and a retained firefighter often varies.

Information Display Used by an IC Working at the Incident: Most of the brigades across UK, traditionally use white boards and markers fixed inside the command support vehicle to maintain information that allow collaborative incident planning with other staff of the incident command team. This board usually carries summarised resource information, status of various fire fighting operations. It is also used to sketch information related to local surroundings (Fire Service Manual Volume 2: Incident Command, 2008).

Information Display Used by SCs Working at the Incident: Currently, apart from having occasional access to information posted on the white boards located at the command post and the BA boards located nearby to their own sector, there is no other designated mode of information display support available for the use of SCs.

Information Display Used by a Working BAECO:



Figure 5.2: Traditional BA Entry Control Board

Currently, upon arrival BAECOs use the support of the BA entry control board as their main information display. Except for a few brigades, such as Leicestershire, most other FRS brigades in the UK use a white board, which is only capable of storing and displaying handwritten information (Figure 5.2).



Figure 5.3: DragerMAN PSS Merlin Electronic BA Board Used by the Leicestershire Fire and Rescue

But as practiced by the Leicestershire FRS, other brigades are also looking forward to use some form of an electronic telemetry such as DragerMAN PSS Merlin (Drager, 2008) to display and maintain BA entry control related information (Figure 5.3).

Limited Use of Visual Aid by a Working BA Wearer: Although countries like USA have done some previous research work such as “Fire” Project (Wilson et al., 2005) to adapt Head Mounted Displays (HMDs) for frontline firefighters, there is hardly any evidence of use of such devices in the UK. The only display device currently used by the BA Wearers in the UK is the Thermal image Camera, which is considered as one of the best state-of- art devices used during the response operations.

Feasibility of Using Visual Aid for BA Wearers: There are many comments such as below captured during the information gathering exercise about the use of a thermal image camera.

Interviewee 5 (Task Capturing Interviews): *It is true that we don't like too much technology...but you see we never refuse to use the right gadget if it genuinely support our work.....classic example is the use of thermal image camera....you see we are ready to sacrifice some precious moment of our operational time to stop and use it...*

Interviewee 6 (Task Capturing Interviews): *You can't beat the service provided by the thermal image camera in terms of providing information in a dark smoke filled area. For my knowledge, it is the ultimate information machine for us for last few years. Almost all the fire engines in our station now carry one of them without fail.*

Interviewee 13(Goal Capturing Interviews): *For us no technology except the thermal image camera to capture what is happening during the fire. I consider it as a god given thing for a BA wearer.... It must have saved many lives for its short period of use in the brigades.*

These comments suggest that although firefighters are reluctant to use any sophisticated equipments other than the most essential; if they have the right device at the right time they will take the opportunity of using such a device. Although it requires the use of both hands to operate, firefighters are not reluctant and in fact, have shown their liking to use the thermal image camera for longer duration.

Risk of Excessive Focus on Visual Aid Used by BA Wearers: It was revealed that despite its benefits, if a BA Wearer focuses attention continuously on a display such as a thermal image camera, there is a tendency to easily lose his/her attention to the other things happening around. The following comments captured from the transcripts during the information gathering justify the risk of focusing for long durations on an interface such as a thermal image camera.

Interviewee 5 (Task Capturing Interviews): *So you have seen the gadget, it is wonderful isn't it.... But there are some negatives to it...these days we have become addicted to it and sometimes ignore what is happening under our feet or just in front us. Sometime within seconds you may be in trouble for example you may fall into a hole in the floor. If you are talking about a hole located on any of the floors.... located above the ground floor of a high-rise..... this can be fatal.*

Catalogued Field Note Ref. 4.30 based on the Observations made during BA Wearer Training on 21st (Day 6) July 2008: *As BA trainers we always keen to educate BA Wearers, especially how they should use the thermal image camera. Initially most of them get addicted. It becomes a third eye for them so they try to totally depend on it. Unfortunately, this avoids them by doing their routine procedures. For example, they may look far but not what is happening just in front or just above you. This is actually a high-risk. So we always ask them to use it whenever essential but not to use it as a third eye.*

Communication Technology Used by Fire Fighters during Operations: For all the firefighter jobs, apart from the face-to-face verbal communication and use of hand held two-way radio communication devices, no other device is used for communications. Even for the BA Wearers in operation, communication with the external world totally depends on listening and speaking to a two-way communication device. *Catalogued Field Note Ref. 4.4 based on the Observations made during BA Wearer Training on 13th July 2008 (Day 1)* (Appendix 5.1) justifies the above argument. DFRS is currently testing the use of head mounted speakers and microphones to replace the traditional two-way walkie-talkies. Also, the observations made during the firefighter training sessions in DFRS revealed that they plan to use a throat operated microphone with a speaker attached to the ear to replace their traditional two-way radio devices. It was further revealed that several metropolitan FRS brigades such as London are already testing the feasibility of the use of throat operated microphones to cut down the excessive incident ground noise during the communications. Despite the above efforts to use new technology, two-way radio is the primary means of information exchange between BA Wearers and their BAECOs, Crew Commanders and other superiors.

Information Display Devices and Technology for Future ICs and SCs: Currently, under the “New Dimension” program, FRS brigades in the UK are investing in Enhanced Command Support (ECS) vehicles, which are to be deployed as the mobile IC rooms during large incidents (Figure 5.4). These vehicles will become the mobile command post for IC in the near future.



Figure 5.4: New ECS Vehicle

These vehicles carry large Liquid Crystal Display (LCD) monitors to be used by the IC team during the management of the fire incidents (Figure 5.5). Most of these displays are touch screen enabled so that users can interact easily and rapidly. In the future, these LCDs are to replace the traditionally used white boards fixed at the command support post.

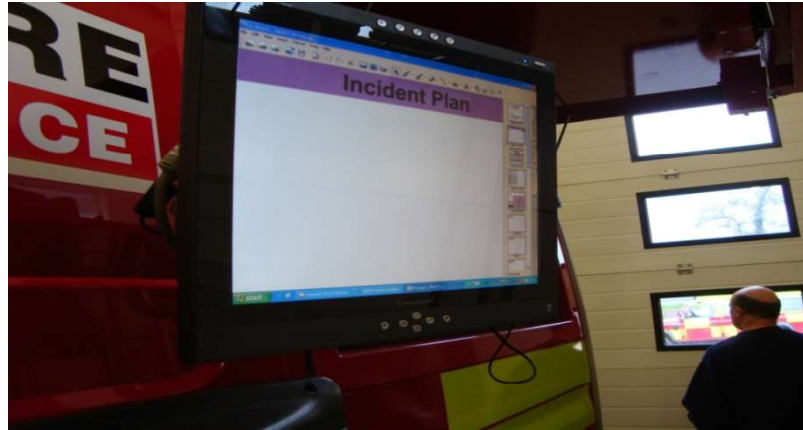


Figure 5.5: Large LCD installed in the ECS Vehicles

Furthermore, some of the vehicles already carry mobile devices, touch screen enabled state-of-art rugged laptops with the option of wireless internet connectivity (Figure 5.6). It is expected that in the future SCs will have the support of the software installed in these laptops during their operations. All the brigades in the East Midlands region have started installing and developing some Geographical IS (GIS) based software in their new command support vehicles. This software uses the support of geographical software APIs (Application Programming Interfaces) available in the public domain such as *Google Maps* (Google Maps, 2009) or with the support of proprietary APIs such as *Cadcorp* (Cadcorp, 2009).



Figure 5.6: State-of-Art Laptops Installed in the ECS Vehicles

Trend of Using State-of-Art Information Display Devices by the Senior Officers on the Move: At present it was observed that there is a significant increase of senior fire officers to carry a PDA type of handheld mobile device to access information and plan their activities. It was also revealed that Leicestershire and Nottinghamshire are investigating the possibility of providing rugged laptops with mobile internet facilities to their senior officers who are frequently deployed as the IC to large incidents.

State-of-Art Information Display Devices for Fire Engines (Tenders): Under the “FireLink” project, brigades of the UK FRS intend to equip all the fire tenders with Mobile Data Terminals (MDT) having a display capability equivalent to that of a new generation laptop (Figure 5.7).



Figure 5.7: Mobile Data Terminal Installed inside the Fire Tenders

Mode of Transport

Officers belonging to the job roles of BAECO and BA Wearer often use the fire engines as their mode of transport to arrive at the incident, whereas most of the senior officers use their official vehicle to reach the incident.

5.3 Design Decisions and their Application

Having considered the information requirements elicited in Chapter 4 for four firefighter job roles, the above considered interface design guidelines, principles and the contextual factors unique to fire emergencies led to several tailor-made design decisions that should be appropriately adopted into the development process of the human computer interface mock-

ups. The following paragraphs of this section explain the details of the specific design decisions made. With the support of some of the relevant interfaces proposed, it also explains and illustrates the details of how these decisions are applied to the development of human computer interfaces for fire ER situation.

5.3.1 Provide SA Support Before and After Arrival to an Incident

The information needs identified in Chapter 4 for each job role, indicate that from the moment when they receive the call for an incident, all four firefighter job roles expect some form of information to support and enhance their incident related SA. Therefore, it is decided to develop interfaces capable of providing necessary SA for all the job roles:

- 1) Before firefighters reach the incident premises
- 2) After arrival when they carry out their individual jobs

5.3.2 Enhance SA related to the External and Internal Context of an Incident Premise

Careful investigation of the information requirements of all four job roles revealed the need of the following common sources of information to enhance SA.

Information Sources Capable of Enhancing External SA

- Traffic Information
- Water Related Resources
- Fire Tender/Vehicles Related Physical Resources
- Human Resources of the FRS
- Human Resources of other Agencies
- External Cordons and Sectors
- Important External Locations
- Important External Organizations
- External Risks and Hazards
- External Operations
- Weather

Information Sources Capable of Enhancing Internal SA

- Internal Risks and Hazards
- Important Internal Locations
- Casualty Related
- Salvage Related

- Internal Fixed Resources and Installations owned by the Building
- Building Structure Related
- Physical Resources belonging to the FRS and other Agencies
- Human Resources of the FRS
- Human Resources of other Agencies
- Internal Operations
- Internal Sectors

At some point in time during the incident progress, there is a possibility that members representing all four job roles may need the support of information generated by the above sources of information in combination of several of them or in isolation, to form Level 1, Level 2, and Level 3 information leading to their respective SA. Therefore, having considered the nature of various sources of information, it is decided to develop the interfaces in such a way that each one of them is capable of presenting the information to enhance the SA related to the 1) context and operations carry out inside the incident premise (Internal SA) or 2) context and operations carry out outside the Incident Premise (External SA) or 3) both the Internal and External SA at once.

5.3.3 Develop Common Layers of Information

As explained in Chapter 4, each GDI diagram provides the comprehensive information needs of a particular firefighter job role related to a particular goal. The collection of information captured for each goal consists of information needs of firefighters having different levels of experience for a particular job role. Therefore, it can be assumed that findings under each GDI diagram possibly contain almost a complete set of information that needs to support of achieving a particular goal. Importantly, achievement of a goal is not instantaneous; some of them may take few seconds others may take minutes. Sometimes it can take even hours or days to achieve a goal in a long duration incident. Therefore, it is not difficult to understand that for a particular goal, a particular firefighter may not need to have the support of all the identified information needs in one single moment of time. It may spread out over a period depending on the type of goal he/she tries to achieve. In addition, it is important to understand that to achieve a particular goal, an individual firefighter belonging to a particular job role may not need the support of the all the pieces of information identified. One of the main reasons for this can be differences in their individual level of experience and skill as it is identified that during an incident,

firefighters working for a particular job may have different set of skills. The following comments made during validation of GDI diagrams justify this argument.

Interviewee 4(IC):..... don't expect us to use all the information listed under one particular goal at once... it is very difficult to predict exactly which information we need and exactly which moment of time we need them...but yes we may need them at a particular moment of time before we reach our goal..... So whatever the system you try to develop it should not try to deliver them at once..... it is important.....

Interviewee 3(BAECO): Yes of course your GDI diagrams are very comprehensive it contains most of the requirements that can be useful to support any type of a BAECO having different needs... mainly due to their individual experience differences.....Butyou have to be very careful nobody can predict what are the exact information needs of a particular individual...of course I'm sure you can find them in your identified list for each goal But the problem is that a particular individual may not need the support of all of them.... Some time yes but more often it will be a sub set of the collection.... What I'm trying to say is that ... you should provide some option that when a fire fighter want the support of these information related to a particular goal he or she should have a very good choice so that particular individual can select what they want....but make sure they have access to all the information needs in the list but the choice of selection must be done by the fire fighterthis is very very important.

The above explanation related to the information needs of firefighters clearly indicates that interfaces to be developed should provide the freedom for users to select information according to their individual preferences. They should have their own choice to select information among all the identified pieces of information for a particular goal.

Careful observations of the information needs of various firefighter job roles show the repetition of information needs. Often, information repetition is evident among different goals of a particular job role and among similar goals belonging to different job roles. For example, consider the information needs across various job roles for the external information source of *traffic information*. As shown in Figure 5.8, repetition of needs for traffic related information is identified among different job roles and different goals. Similarly, repetitions are identified across all the other information sources for all other job roles. Having considered the repetitive information needs across goals and the job roles and the need of providing the option so that individual users can flexibly select their choice of

information, it is so decided to develop common layers of information. Regardless of the job role, these layers will contain some common information capable of satisfying repetitive information needs identified across different goals of a single job or across all four job roles.



Figure 5.8: Information Requirements related to Traffic Information

As shown in Figure 5.9, any unique requirement of an individual firefighter relevant to a particular goal or a particular job could be achieved by superimposing several appropriate layers of information. This design concept will enhance the end-user freedom in selecting the type and the number of information layers according to their individual preferences. Sometimes, in addition to the common layers, layer/s containing some information unique

to a job role may have to superimpose appropriately to augment the information presented in the common layers. Often, the bottom most layer of an interface that needs to display Level 2 and Level 3 information needs in relation to a geographical location will consist of an appropriate map layer.

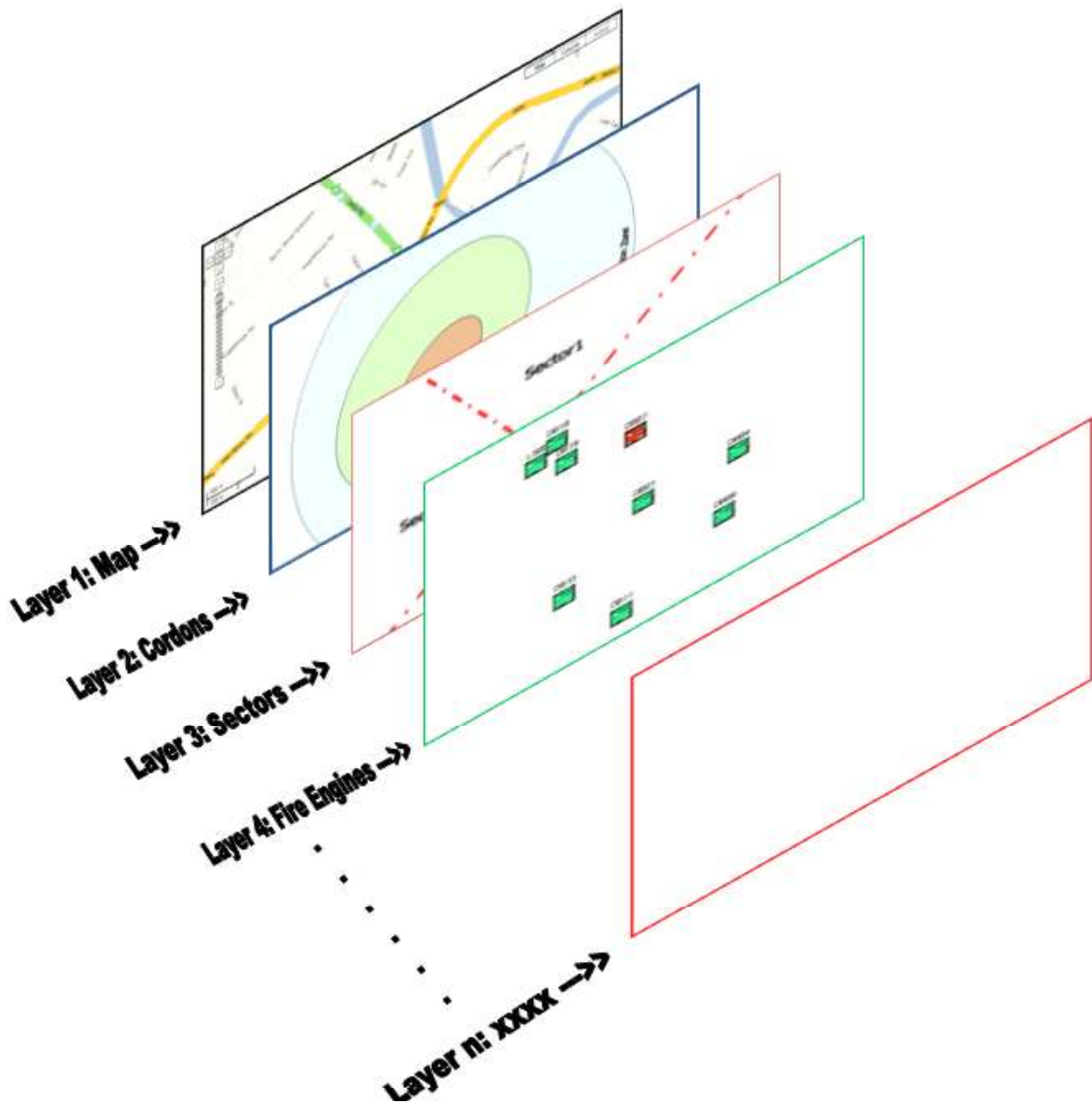


Figure 5.9: Enhanced SA via Superimposed Common Layers of Information

This particular design decision not only supports end-users to enhance their SA quickly but also helps the interface developer to reduce the workload to a significant level during the interface development. Therefore, throughout, efforts are made to reduce the number of interfaces to be developed by promoting a layered architecture consisting of common information displays. The proposed layered architecture is primarily driven by the principles of “Mashups”. A “Mashup” is a website that combines content from more than

one source (multiple websites) into an integrated experience (Taivalasaari and Mikkonen, 2008). Huang and Yang (2009) describe the importance of automatic generation of “Situational Mashups” when the end-user is roaming in a ubiquitous computing environment and executing different tasks. Therefore, conceptually the proposed information layers show the characteristics of a “Situational Mashup.”

5.3.4 Maintain Multimodal Presentation of Information

The contextual considerations made earlier indicate some unique characteristics that require appropriate adaptation of the SA oriented design principle: *Take advantage of parallel modes of processing*. Thus, depending on the level of impact of various contextual factors for each firefighter job role, it is decided to introduce multiple modes of information presentation appropriately to minimize the cognitive overloading of visual, audio or tactile capacity of the end-users. For example, having considered the level of impact of various contextual factors related to a frontline firefighter, it is decided to propose interfaces with multiple information presentation modes: voice and visual to support during their frontline fire and rescue operations. Similarly, when consider the contextual factors related to other job roles it is evident that it is not feasible for the members of those job roles to maintain their attention continuously to a visual interface. Therefore, it is decided to propose the support of voice alerts under exceptional conditions so that the attention of ICs, SCs and BAECOs could be shifted appropriately to a visual display for more comprehensive information. The specific proposals made in regard to this particular decision will be discussed in the following section.

5.3.5 Decisions Related to Selection of Devices for Information Presentation

The considerations arising from the unique contextual factors also led to the following design decisions specifically related to display and delivery of information for the selected firefighter job roles. Prior to the design of interfaces, it is considered as important to make the decision on the type of devices onto which the interfaces proposed for each job role are going to be deployed. This allows the designer to understand the requirements related to physical size, controllability, accessibility and other attributes that could have a direct impact on the actual design of the interfaces.

Information Presentation Device for Fire Fighters On-route to an Incident: Mock-up interfaces for both ICs and SCs who are on-route to an incident are developed in such a way

that they can be accessed via a laptop or a mobile data terminal. In contrast, for the use of BAECOs and all other fire crews who are on-route, it is considered as ideal to deploy the relevant human computer interfaces on to the mobile data terminals mounted on the fire tenders.

Information Presentation Device for an IC (after arrival): The interfaces proposed are intended to be deployed onto the large LCDs mounted on the command support vehicles when an IC arrives at the incident. For the job role of an IC, this is considered to be appropriate as observations suggest that an IC is always mobilized in and around the area of command support. To accommodate the need of receiving useful voice alerts, it is proposed to use an appropriate type of head mounted set of speakers for IC jobs.

Information Presentation Device for an SC (after arrival): For the use of SCs, human computer interfaces are intended to be deployed on to a rugged laptop, which can be accessed in difficult contextual conditions since SCs are usually mobilized around the bridgehead area or a similar functional location away from the command post. To accommodate the need of receiving useful voice alerts, SCs are also proposed to use an appropriate type of head mounted set of speakers.

Information Presentation Device for a BAECO (after arrival): Having considered the work behaviour of the BAECO, this study intends to deploy the human computer interfaces related to the BAECO on to a LCD panel similar in size to the semi-automated BA board used by the Leicestershire FRS. It is also proposed to use an appropriate type of head mounted set of speakers for BAECOs so they can receive useful voice alerts.

Information Presentation Device for a Frontline Fire Fighter (after arrival): Since firefighters use both their hands and their legs to undertake their operational activities, it will be very difficult for them to use their hands to operate any other device. Furthermore, in smoke filled dark places, where search and rescue missions become more difficult, their eyes become a crucial sensory device. Having considered the user characteristics such as continuous mobility, higher levels of hands free and eyes free requirements, the decision on the mode of information delivery for frontline firefighters become challenging. Non availability of a proven technology to benchmark makes this decision even more difficult. The applicability of mobile computing solutions proposed by Wilson et al. (2005) and

Bretschneider et al. (2006) to provide visual information seem impractical, since these concepts entirely depend on the use of the visual medium for information delivery and need significant visual attention. Furthermore, there is no explanation on the means of control of the device. Therefore, it is important to consider other technologies that allow eyes of the firefighters to be freed to a greater extent as well as to recognize technologies capable of providing some means of appropriate control of the device. This is important as such synergic systems will allow firefighters to concentrate more on their search and rescue operations. Having considered the behaviours of frontline firefighters, the pros and cons of using a display device and considering their extensive use of voice communication during the operations, this study recommends a multimodal interface embedded with both audio and visual for frontline BA Wearers. Furthermore, considering the reluctance and difficulty to use both hands to control the device, this study proposes to control the visual interface via simple voice commands. Though, as discussed under the contextual considerations, the incident ground has been identified as a very noisy place. Therefore, to control a device with voice may be quite impossible. Nonetheless, it was revealed that a few brigades of the UK FRS are already testing the use of throat operated microphones to cut down excessive noise. Having considered such technological possibilities, this study proposes the use of throat operated microphones to replace the natural voice to control the BA Wearer visual interface with the expectation of reducing the unwanted noise. Furthermore, the delivery of audio information to the firefighters is proposed to be via a head mounted set of speakers.

5.3.6 Develop Interfaces to Enhance Level 1 SA (Perception)

GDI Diagrams developed in Chapter 4 indicated that for each job role, number of information are required to enhance the Level 1 SA during fire ER. SA Oriented design principle: *Support Global SA* also accentuates the importance of developing interfaces capable of enhancing Level 1 SA (Perception). Therefore, for each job role, it is decided to develop interfaces primarily capable of presenting the Level 1 information needs. These interfaces will support an end-user to maintain a global picture relevant to a particular job role at any given time of the fire emergency while making perception of specific problems salient and facilitating diagnosis and information gathering relevant to these problems (Yang et al., 2009b; 2009c). Thus, with this type of interfaces firefighters will be able to have a high-level summarised overview of the situation across their goals. Simultaneously, detailed information related to the firefighter's current goals of interest is also provided as required.

The interface: “Dashboard,” shown in Figure 5.10 is selected to explain the application of the above design decision. The “Dashboard” is capable of displaying Level 1 SA information primarily useful for an IC. Careful investigation of the information needs elicited from the ICs indicates the importance of having summarised information covering the overall scope of the incident. In fact, almost all the validated GDI diagrams obtained for the job role of IC show the need for summarised information covering the whole incident. During contextual considerations, it is also identified that throughout the incident, ICs often use the support of summarised overview of the incident updated on a large white board. Consequently, to fulfil these needs of ICs, it is decided to adapt the above explained SA oriented design principle to develop the “Dashboard” interface.

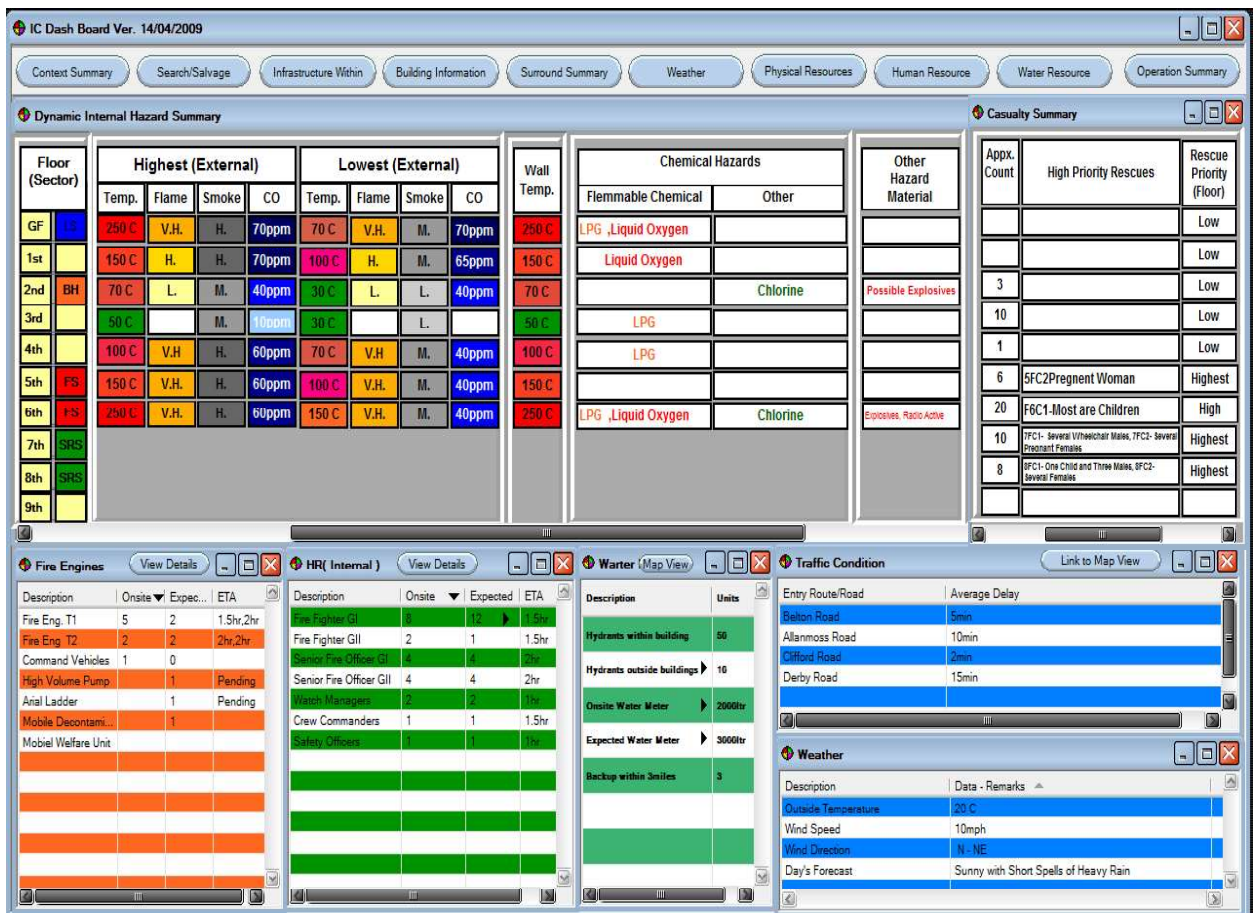


Figure 5.10: The “Dash Board”

With the support of this interface, an IC will be able to dynamically access summaries of the prevailing situation of an incident generated across different categories of information. At any given point of access, this interface is capable of showing following ten categories of summarised perception information:

- Context Summary (Internal/External): Information related to dynamic and static contextual parameters located internal or external to the incident premise. This includes various types of hazards.
- Casualty and Salvage Summary: Information related to the identified casualties and items to be salvaged.
- Operation Summary: Summary of all the incident related operations.
- Surround Summary: Summary of information related to the surroundings of the incident location. This includes summary of traffic, vulnerable buildings and important locations.
- Fixed Infrastructure: Significant infrastructure facilities and installations located within the incident premises.
- Physical Resources: Summary of dynamic and static information on physical resources belonging to FRS, which are at the incident site or are expected to arrive shortly.
- Human Resource: Summary of 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.
- Building Information: Summary of construction of the incident premise.
- Water Resource: Summary of available water resources belonging to fire & rescue services or others.
- Weather: Summary of dynamic information related to weather in the vicinity of an incident.

As shown, under each category of information, an IC will be able to receive a basic perception of a variety of parameters (Yang et al., 2009b). For example, dynamic internal hazard summary provides an overall perception of the important parameters such as temperature, flame levels, smoke levels and carbon monoxide levels inside the building. Furthermore, it also provides the summarised Chemical and Non-chemical hazard material information. Importantly, as shown, when needed, perception information related to many categories of information such as hazards and hazardous materials, salvage, casualty and resources could be organised across all the floors of the incident building. Moreover, an IC will be able to acquire more specific perception information related to each of these categories according to their preference by clicking on top of the appropriate location of the interface corresponding to the preferred element of information. This will allow an IC to call additional interfaces containing Level 1 perception information relevant to specific contextual element or parameter located either inside or outside the incident premise.

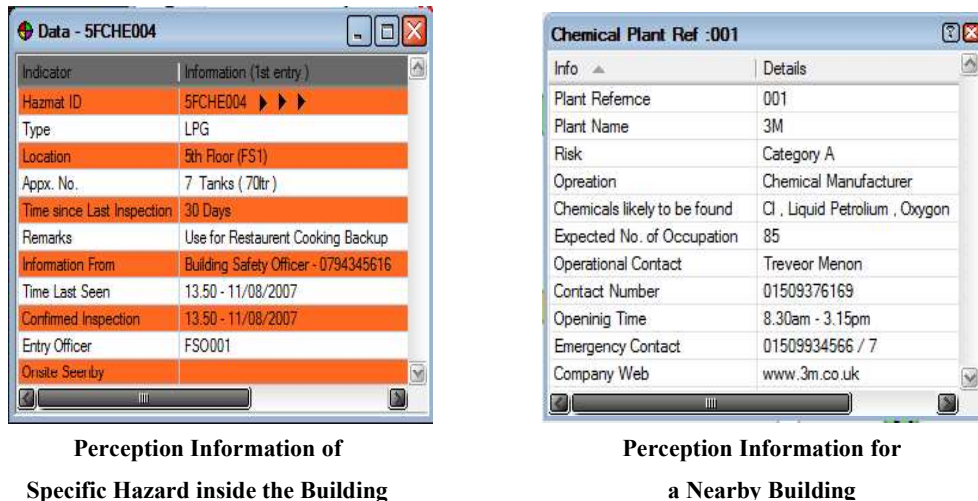


Figure 5.11: Interfaces to Display Perception Information on Specific Contextual Elements

For example, Figure 5.11, shows the interfaces developed to display specific perception information related to two items; specific internal hazard of a building and specific building located nearby the incident premise. This type of interfaces supports ICs to further enhance their Level 1 SA. Corresponding to other design decisions, details of such functionalities are explained later.

Similar to the above example, several other interfaces capable of enhancing Level 1 SA of all four job roles are developed. With the use of these interfaces, firefighters will be able to enhance their Level 1 SA by receiving perception of many contextual parameters in relation to their job responsibilities and operations at any given moment of time.

5.3.7 Develop Interfaces to Enhance Level 2 SA (Comprehension)

As explained in the Chapter 4, for each job role, number of information needs required to enhance the Level 2 SA during fire ER were identified. SA oriented design principle *Present Level 2 SA information directly (support Comprehension)* also clearly indicates the importance of developing human computer interfaces capable of displaying the information to enhance the SA at the comprehension level. Therefore, for each job role, it is decided to develop appropriate interfaces consisting of the Level 2 information. These interfaces will provide the appropriate comprehension by displaying the information that is processed and integrated to the Level 2 SA (Yang et al., 2009b; 2009c).

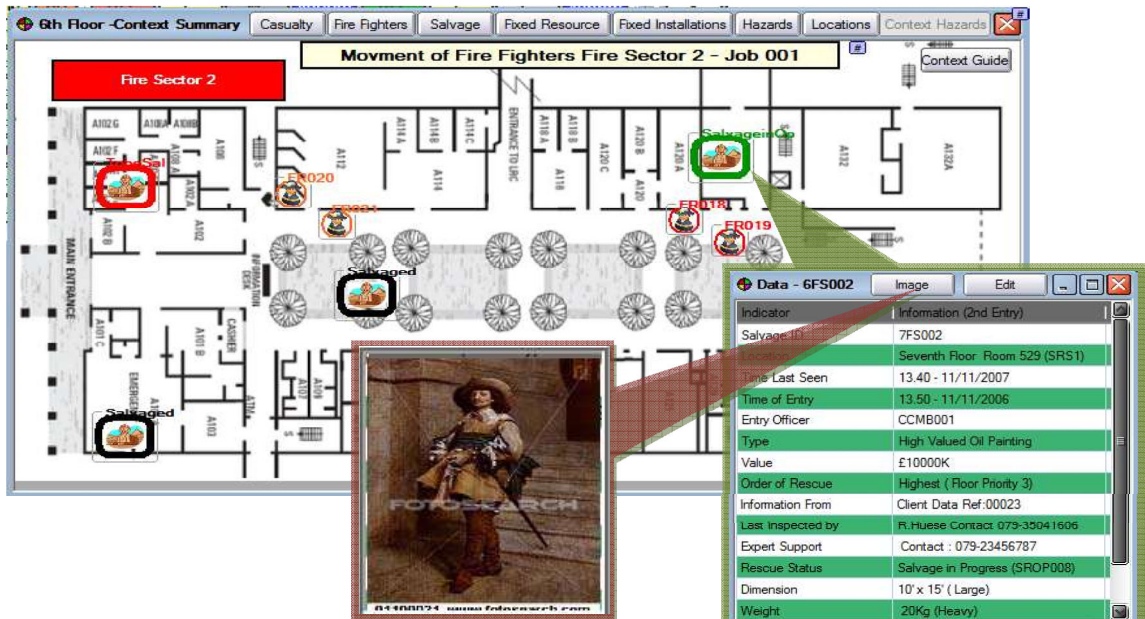


Figure 5.12: Interface Enhancing an IC's Level2 SA related to the Internal Context of an Incident

The interface shown in Figure 5.12 is selected to explain the application of the above design decision. This particular interface is capable of displaying various Level 2 information useful for a SC who is in charge of conducting a salvage operation to rescue some valuable items located within a particular floor of a building. Careful investigation of information needs elicited for the SCs indicates the importance of having appropriate level of comprehension when they need to carry out salvage operations within an incident premise. Thus, to fulfil such needs of SCs, it is decided to adapt the above explained SA oriented design principle to develop this particular interface. In this particular interface, a SC would be able to enhance his/her Level 2 SA by integrating static building layout information with graphically represented dynamic information such as movement of the firefighters who carry out the salvage operation together with the location of items to be salvaged to form a comprehensive picture of the operation. Since this interface should display some location related information needs, the detailed building plan of that particular floor area becomes the primary information layer of the interface. In addition, by using different shades of colours and text this interface shows the status of the salvage operation for each item to be salvaged. This interface is also 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. As shown in this particular example, by clicking on the icon representing an item to be salvaged, the SC is able to obtain more specific

perception level information related to a particular item to be salvaged. This information includes an actual picture of the item, dimensions, manpower requirement for handling, weight and experts support contacts.

Similar to the above example many other interfaces capable of enhancing Level 2 SA of all four job roles are developed. Rather than presenting a set of isolated information mostly via numbers and text as in the perception level, with this type of interface, dynamic information is meaningfully integrated with static information using graphical presentations to provide the appropriate level of comprehension of the situation at any given moment of time to further improve the SA.

5.3.8 Develop Interfaces to Enhance Level 3 SA (Projection)

As explained in the Chapter 4, for each job role, several information needs required to enhance the Level 3 SA during fire ER were identified. Also, the SA oriented design principles *Provide assistance for Level 3 SA Projections*, clearly indicates the importance of developing interfaces capable of enhancing Level 3 SA (Projection). Therefore, for each job role, it is decided to develop interfaces capable of presenting the Level 3 information needs. By developing these interfaces, projection of future events is supported by providing the firefighters with information on current and past trends on various situational parameters (Yang et al., 2009b; 2009c).

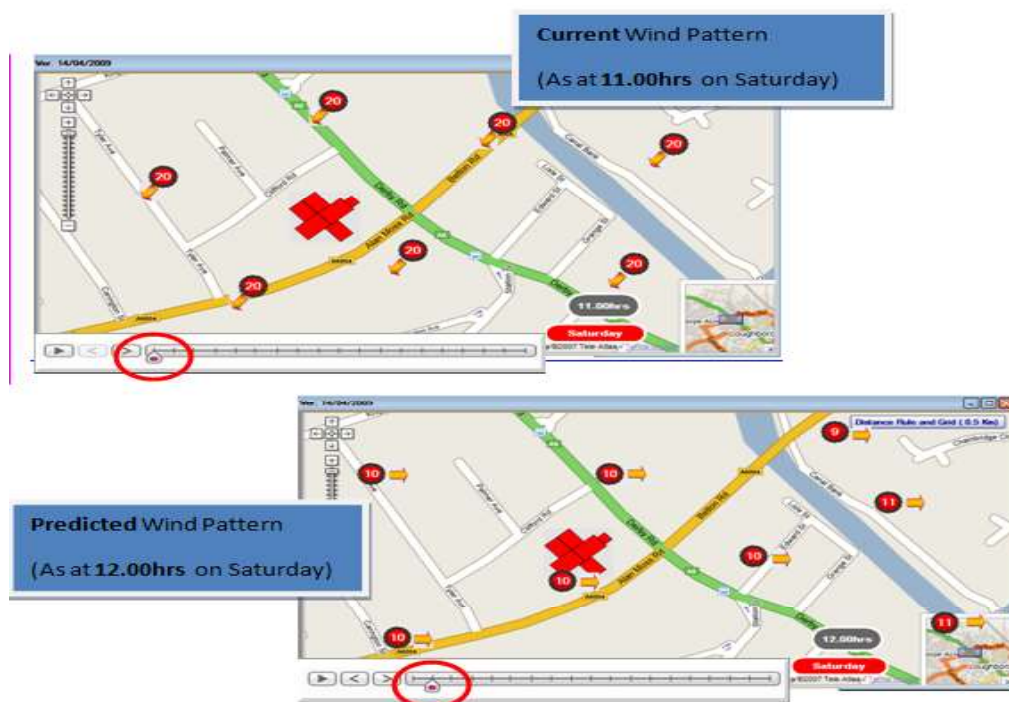


Figure 5.13: Interface Capable of Providing Level 3 SA on Wind Patterns

The interface shown in Figure 5.13 is selected to explain the application of the above design decision. This particular interface provides Level 3 SA to an IC, enabling him/her to make accurate predictions on an important environmental parameter of wind direction under the information category of weather. As shown, by clicking on the *play button* or *forward button* this particular interface will be able to display the predicted wind pattern around the incident vicinity, allowing IC to project for the near future.

Similar to the above example, several other interfaces capable of enhancing Level 3 SA of all four job roles are developed. Together with the summarised information interfaces enhancing the perception and the interfaces capable of enhancing comprehension of the firefighters, this type of interfaces are capable of providing a higher-level of SA that will assist all the four job roles in making difficult predictions with confidence at any given moment of time of the emergency.

5.3.9 Promote Goal Oriented Organization of Information

As explained in the SA oriented design principle: *Organise information around goals*, it is important to organise the interfaces in such a way that they present the information supporting the decision-making to achieve a particular goal. Thus, it is decided to develop interfaces so that firefighters of all four job roles are provided the option of seamlessly organizing their Level 1, Level 2 and Level 3 information around their goals.

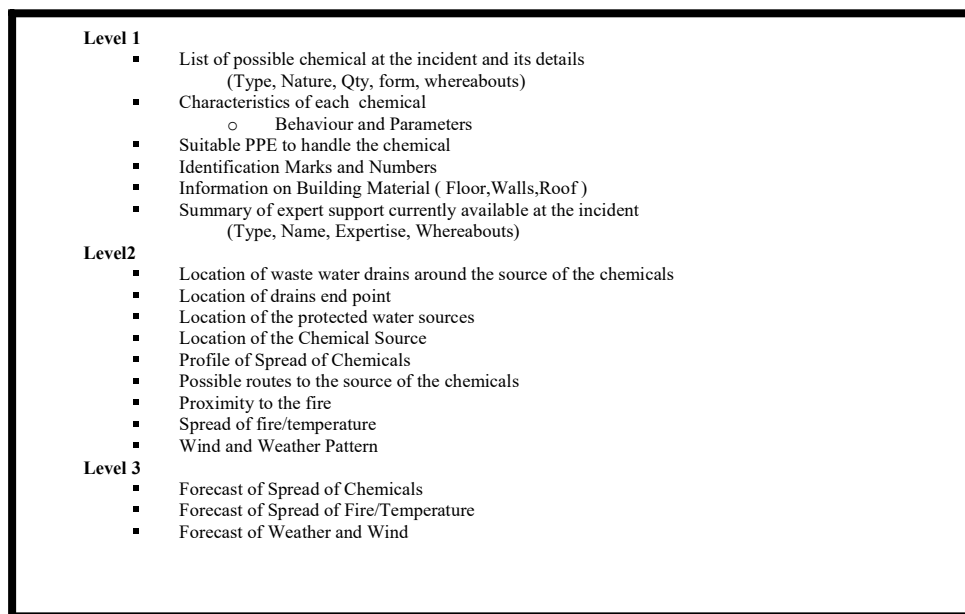


Figure 5.14: Information Requirements Identified for Sub Goal “Maintain Strategy for Removal or Neutralization of Chemicals”

To explain the application of the above design decision for the interface development process, the information requirements identified for randomly selected IC sub goal “Maintain Strategy for Removal or Neutralization of Chemicals” (Figure 5.14) is considered. As shown in Figure 5.14, information needs identified for this goal consists of some requirements related to the summarised Level 1 information covering the overall incident. Having considered these Level 1 requirements, ICs have provided support of the “Dash Board.” As explained earlier, this interface is capable of displaying summarised information needs related to the entire incident. Therefore, specifically in relation to this particular goal, end-users will be able to call the information related to the above listed Level 1 needs by clicking an appropriate button located on top of the primary display of the “Dash Board.” For example, as shown in Figure 5.15, by calling the *Dynamic incident hazard summary* onto the display, an end-user will be able to enhance perception on the Level 1 information: *A List of possible hazardous chemicals at the incident and its details (Type, Nature, Qty, Form and Whereabouts).*

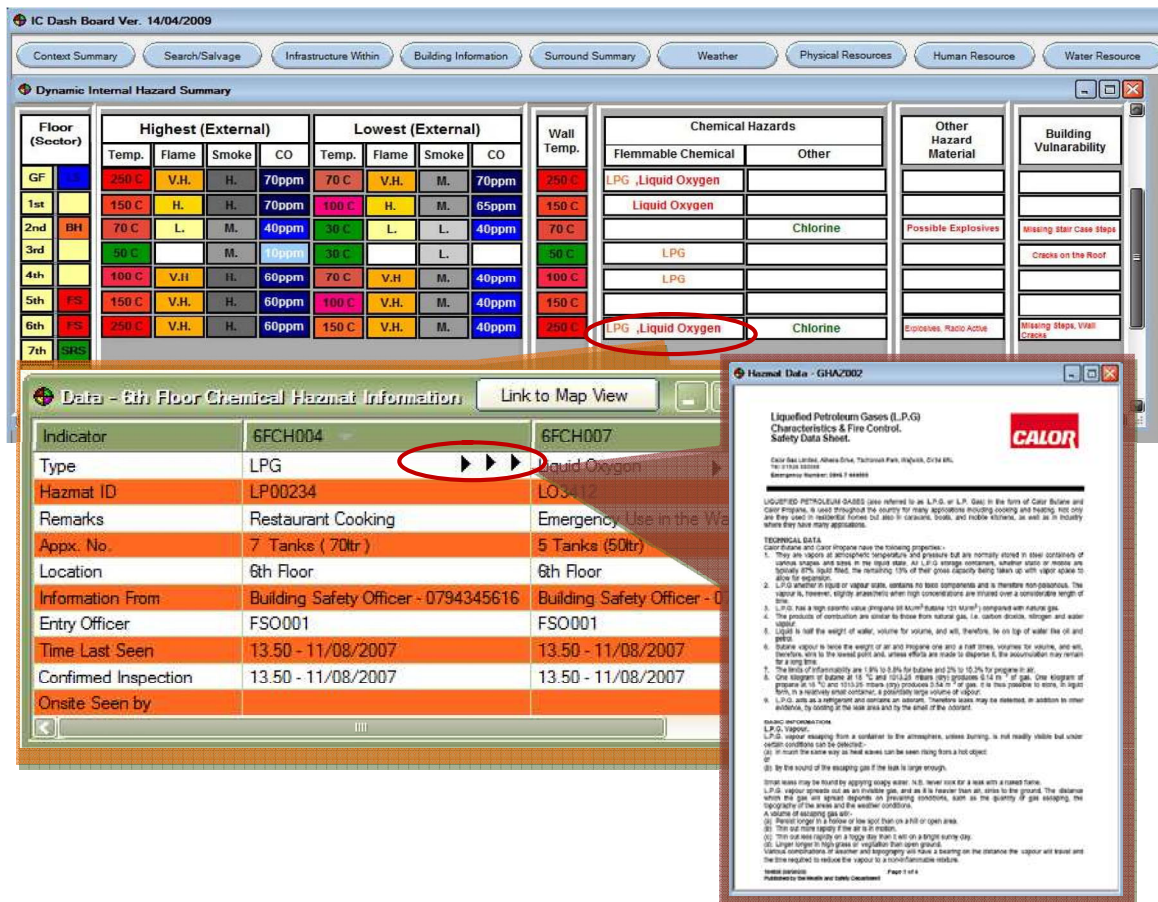


Figure 5.15: Enhanced Perception with the Use of “Dash Board” Interface

As shown, end-users will be able to acquire the summarised information on all the chemical hazards. It also indicates the basic whereabouts of such hazards by providing the floor information. In addition, according to their preference, an end-user is given the facility to call some additional information related to the chemicals located in a particular floor by clicking on the appropriate grid position of the interface. Furthermore, by clicking on the graphical symbol located on this additional display (▶▶▶), end-user will be able to acquire Level 1 information need: *Characteristics of each chemical* in the form of Hazmat Data. Hazmat data is capable of providing the unique characteristics related to a specific chemical. Hazmat Data can also provides the Level 1 information need: *Suitable PPE to handle the Chemical*. Similar to the above explained Level 1 information of this goal, this mock-up is developed in such a way that an end-user will be able to call some of the remaining Level 1 information needs: *Information on building construction materials* and *Summary of expert support currently available at the incident* onto the “Dashboard” interface.

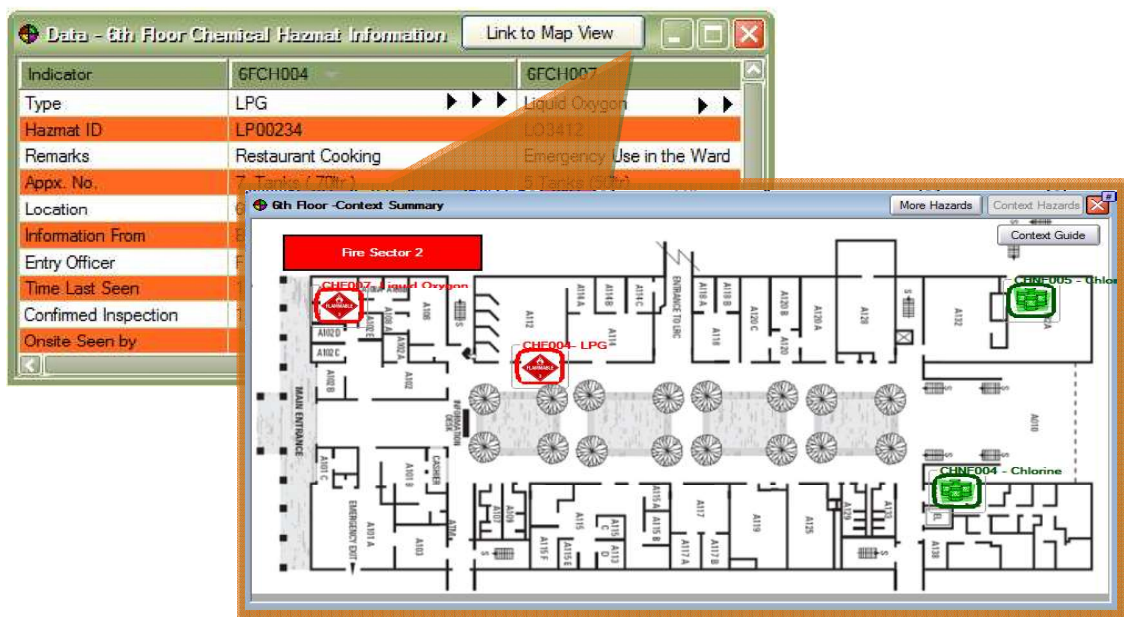


Figure 5.16: Organizing Level 2 Information Related to a Goal

As shown in Figure 5.16, by clicking on the button “Link to Map View,” ICs will be able to call an interface containing comprehensive and in-depth Level 2 information needs related to the goal “*Maintain Strategy for Removal or Neutralization of Chemicals.*” As shown, with this particular information layer capable of displaying the Dynamic Location of Hazard Material, ICs will be able to acquire the Level 2 information need *Location of the chemical source.*

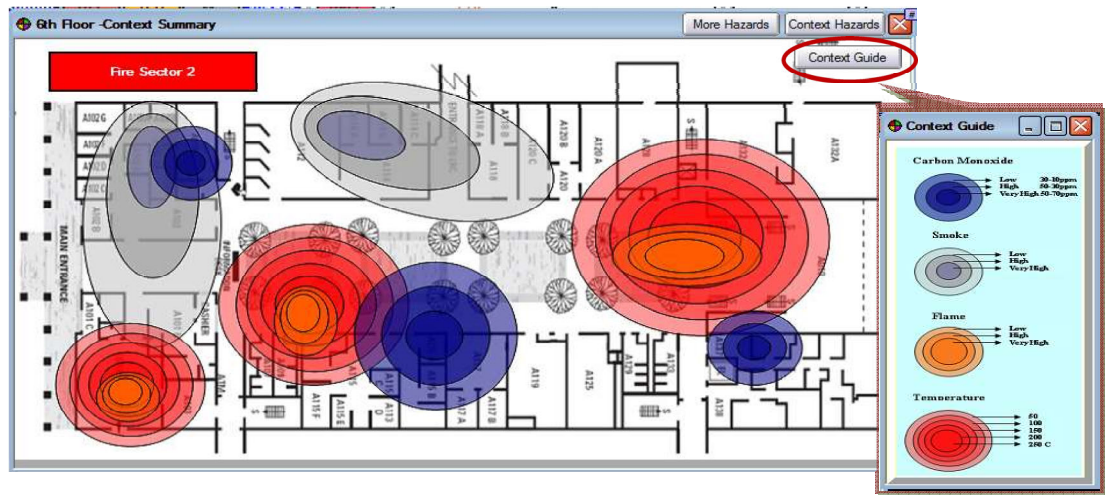


Figure 5.17: Dynamic 2D Display of Hazards due to Temperature, Flame, Smoke and Carbon Monoxide

However, if an IC needs to further enhance his/her Level 2 SA and therefore, needs to acquire the Level 2 information such as *Spread of fire and Temperature, proximity of chemical to the fire and possible routes to the source of the chemical*, then as shown in Figure 5.17, an IC will be able to call an additional information layer, which is a Dynamic 2D Display of Hazards like *Temperature, Flame, Smoke and Carbon Monoxide*. By superimposing this new layer of information on top of the previous layer, IC would be able to generate a combined display as shown in Figure 5.18.

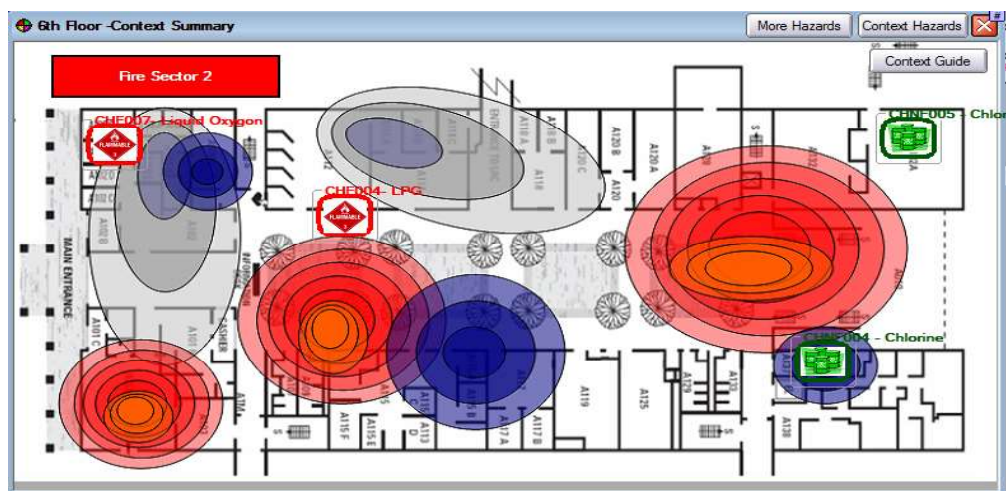


Figure 5.18: Superimposed Layers of Information Related to Chemicals and Contextual Hazards

Similar to display the above explained Level 2 information needs related to the selected goal, this mock-up proposed for IC is capable of calling relevant additional interfaces to display the remaining Level 2 information needs for this particular goal.

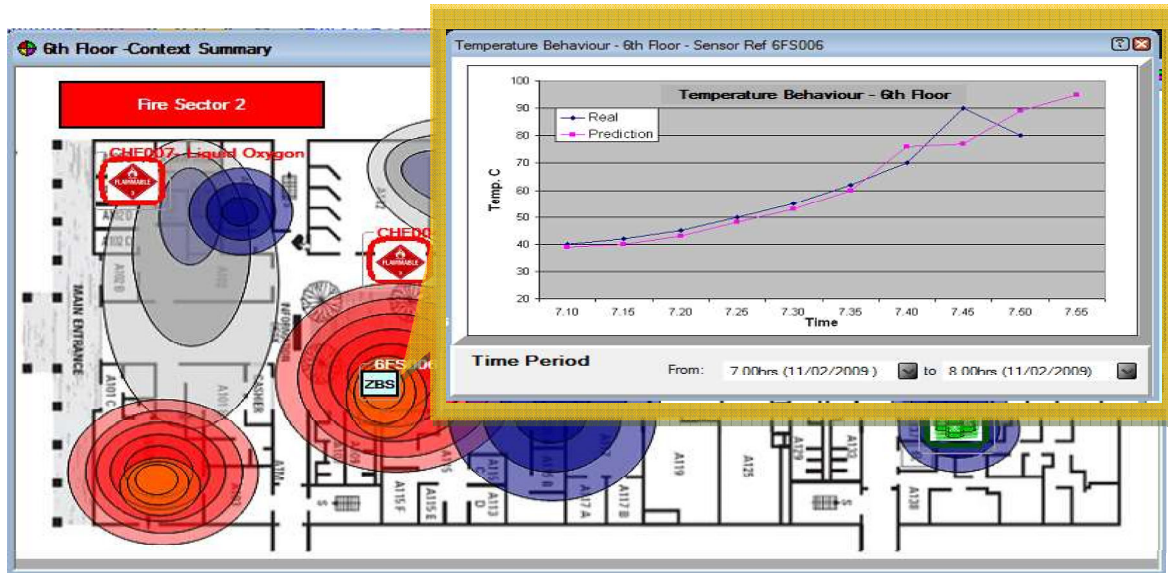


Figure 5.19: Actual and Forecasted Temperature for a Specified Period

In addition to the above explain Level 1 and Level 2 needs, an IC would be able to satisfy his/her needs related to the Level 3 information such as *forecast of the temperature* by calling the interface shown in Figure 5.19. As shown, this interface is capable of displaying the “Current” and “Forecasted” Temperature for a specified period. An IC would be able to click any location on the map and request to display the variation of temperature of that particular location for a selected period. Similar to this particular Level 3 information need, end-users are provided with the support of some additional interfaces capable of displaying remaining Level 3 information needs identified for this particular goal.

As explained above, mock-ups developed for all the four job roles have provided a facility of flexible organization of Level 1, Level 2 and Level 3 information needs around the goals being perused by individual end-users at any given moment of the fire ER operation.

5.3.10 Provide Information to Identify the Changing Priority of the Goals

Having considered the importance of SA oriented design principle *Support tradeoffs between goal-driven and data-driven processing*, it is decided to develop interfaces for all the job roles so that interfaces proposed are capable of indicating the change of the priority of the end-users goals at any given moment of the response operations. By adding such an

option into the mock-ups proposed, end-users will be able to shift their focus to the new goal/s that needs higher attention at that particular situation.

For example, interfaces similar to the “Dash Board” may present a substantially large amount of information at any given moment of time to the users. In such conditions, when the current goal being attended is changing towards a new goal or abruptly changed to a new goal, it is decided to present exceptional conditions or time dependent information (Wickens and Hollands, 2000) to the end-user to attract and shift their attention appropriately. To shift the attention of the end-user appropriately to the goal that needs attention, it is decided to use change of colours, colour shades in combination with text and symbols meaningfully. For example, as shown in Figure 5.20, a progress bar consisting of dynamically changing colour shades and dynamically changing text based numerical values is used to shift the attention of a BAECO towards a particular goal.



Figure 5.20: Display of Time Dependent Information for BAECOs via Coloured Progress Bar with Text

However at the extreme end, especially when end-user’s attention is focused onto a much narrower scope of their operations, attention shift is achieved via appropriate audio or visual alarms or alerts. Importantly, when several such alarms are to be used, necessary means of distinguishing such alarms are maintained.

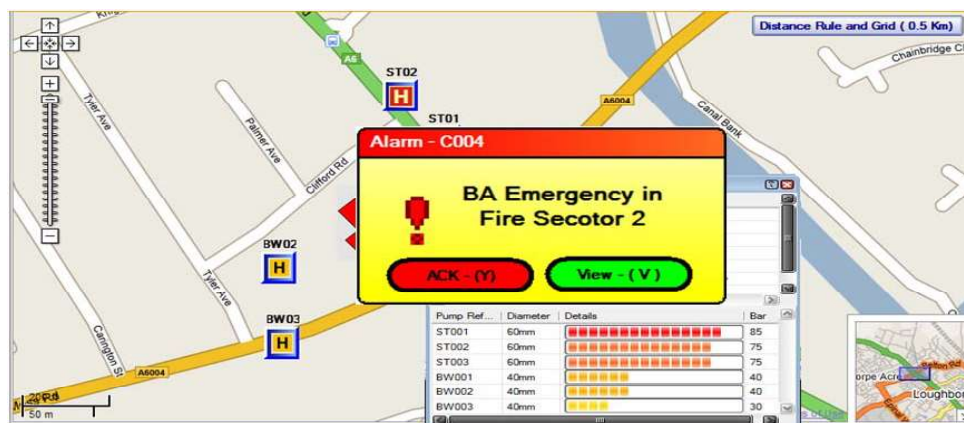


Figure 5.21: Display of Visual Alerts to Shift the Attention to a New Goal with Higher Priority

For example, as shown in Figure 5.21, a situation where an IC is focused onto water resource related goal and using an interface to enhance his comprehension on water hydrants located around the incident is selected. To shift his attention to a high-priority goal due to a sudden emergency occurred in the Fire Sector 2, a prominent visual alert is proposed to be displayed on top of the information layers of this interface. Furthermore, by clicking on the “View” button on the alert, end-user’s attention will be immediately shifted to this important goal by displaying an interface showing the current condition of the Fire Sector 2.

As explained above, appropriate display of the Exceptional Conditions and Time Dependent Information is used throughout the interface development process to maintain the accurate attention of the firefighters due to changing priority of their goals.

5.3.11 Prominently Display Key Information that Trigger Different Classes of Situations

Having considered the importance of SA oriented design principle: *Make critical cues for schema activation salient*, it is decided to display the information prominently that could support firefighters to trigger their minds to understand the critical conditions occur at the fire incident ground. Therefore, for each firefighter job role effort is made to recognize these critical pieces of information among many other Level 1, Level 2 and Level 3 information identified and to display them prominently. However, determining what these critical pieces of information are a challenging task (Endsley et al., 2003b), mainly because firefighters find it difficult to verbalize them. Nonetheless, it is considered as useful to display at least those can be verbalized and are known to be most important.

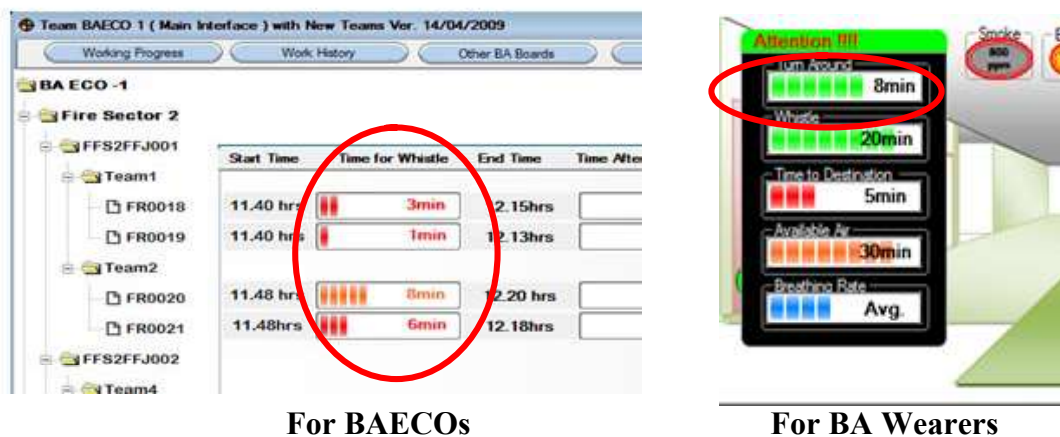


Figure 5.22: Display of “Time of Whistle” Indicator for a BAECO and BA Wearer

For example, one of the most crucial pieces of information described and verbalized by most of the BAECO and BA Wearers is the “Time of Whistle.” Consequently, as shown in Figure 5.22, it is decided to display this particular piece of information prominently on the interfaces proposed for both BAECOs and BA Wearers, throughout their operations. Similar to this example, many other critical pieces of information are identified for all four job roles, and effort is made to display them via appropriate interfaces.

5.3.12 Avoid Unnecessary Extreme Filtering of Information

It is highly unlikely that end-users want to display all the information at once as they like to minimize information overload. However, SA oriented design principle *Use information filtering carefully*, clearly indicates the importance of developing interfaces that avoid unnecessary filtering of information. Particularly during fire ER operations, it was identified that end-users having different levels of experience may use the same interface. However, individual end-users may need different types of information to be call onto this interface to form their individual SA and doing so it would not be possible to depend entirely on the system driven information filtering. Therefore, it is considered as extremely important to consider these individual differences in proposing information filtering schemes. Having considered the possibility of seriously degraded SA due to extreme information filtering, it is decided to introduce a flexible information filtering option, which can be primarily controlled by the end-user rather than the system. For each individual end-user, it is decided to provide an option so that the end-user can decide which type of information to be displayed via a particular interface by default. With this customization option, each end-user could maintain an individual display profile. For example, when considering the “Dash Board” interface, each end-user would be able to decide what categories of perception information he/she initially wants to display on the interfaces.

The screenshot shows a software interface titled "Internal Hazard Summary" with several data panels, each with a checked checkbox for visibility:

- Highest (External)**: A 2x4 grid of data points.

| Temp | Flam | Smol | CO |
|-------|------|------|-------|
| 250 C | V.H. | H. | 70ppm |
| 150 C | H. | H. | 70ppm |
- Lowest (External)**: A 2x4 grid of data points.

| Temp | Flam | Smol | CO |
|-------|------|------|-------|
| 70 C | V.H. | M. | 70ppm |
| 100 C | H. | M. | 65ppm |
- Wall Temp.**: A vertical list of two values: 250 C and 150 C.
- Chemical Hazards**: A 2x2 grid of categories.

| Flemmable | Other |
|--------------------|-------|
| LPG, Liquid Oxygen | |
| Liquid Oxygen | |

Figure 5.23: Information Display Customization for the “Dash Board” Interface

Figure 5.23 shows a part of the customization panel proposed for the interface “Dash Board.” With this customization panel, the end-user will be able to specify the information to be displayed by clicking on the option buttons (). As shown, based on individual preferences, end-user would be able to add or remove an individual, several or a group of contextual attributes for his/her interface. This process of information selection can be repeated for all other categories of information. However, when the incident progresses, end-users have the option of changing their preference for the information to be displayed by selecting new categories of information to replace or augment the existing categories of information. Where appropriate, this type of flexible filtering is proposed for all the job roles, so only the information that is truly not needed to enhance end-user SA could avoid being displayed.

5.3.13 Support Rapid Cognitive Demand Changes

The GDI diagrams developed for the four job roles revealed that the level of detail related to a particular piece of information could vary rapidly for each job role. This is justified, as according to the contextual factors it is evident that cognitive demands of firefighters for information vary as the incident progresses due to changes in the complexity of the incident. Therefore, SA requirements of an individual firefighter could suddenly change from one level to another. Hence, it is decided to design the mock-ups in such a way that they are capable of accommodating the cognitive demand changes of its end-users. Throughout the development, efforts are made to design the mock-ups so that at any stage, the number of steps to call any particular piece of information is kept to a minimum so that end-user could rapidly and seamlessly access any type of information.

For example, application of this particular decision could be explained as shown in Figure 5.24. When the situation related to any particular contextual parameter (5th Floor Temperature) of the incident change rapidly, an IC can use his “Dash Board” as a launching pad to enhance his SA from perception level to the comprehension level. This can be done by just one click, and further with another single click he/she will be able to enhance his/her SA level to the projection level. Also, when the IC wants to go back to his perception level information quickly it will only take another one click from any of the interface proposed. Although it is always not possible to maintain three or lesser number of steps similar to this particular example, a constant effort is made to maintain minimum number of steps to acquire any type information.

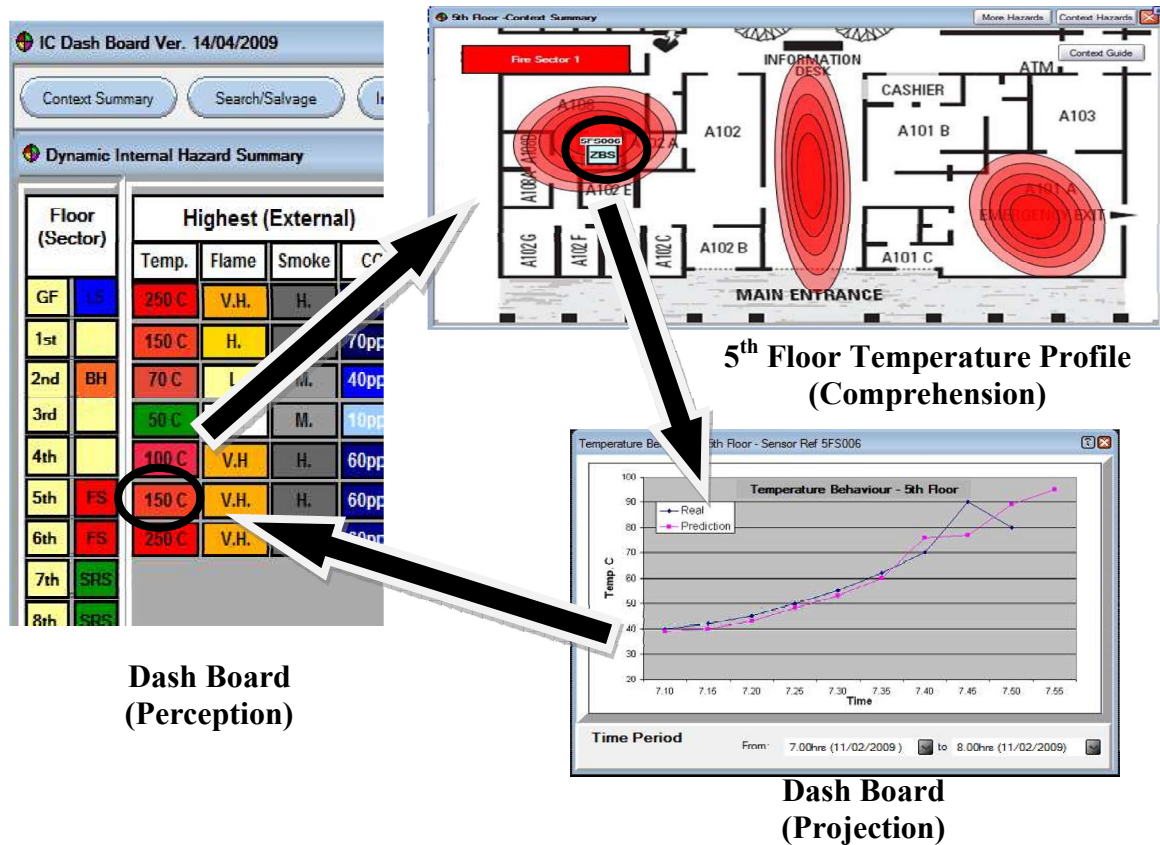


Figure 5.24: Support Rapid Change of Cognitive Demands for Information

5.3.14 Maintain Consistent Navigation Sequence to Access Interfaces

While it is important to provide rapid navigation across interfaces capable of displaying different levels of SA to support the cognitive demand changes, it is also considered as important to maintain some form of consistency during such navigation. Thus, it is decided to allow end-users to perform interface navigation in the same sequence during similar conditions. This is guided by the human computer interface usability guidelines of the National Institute of Health in the U.S. Department of Health and Human Services (Leavitt and Shneiderman, 2006). For example, the sequence of navigation proposed for ICs and SCs to build their SA by calling additional interfaces embedded with Level 2 and Level 3 onto their primary Level 1 information interface “Dash Board” is similar to that proposed for a BAECO to enhance their SA by calling additional interfaces embedded with Level 2 and Level 3 onto their primary Level 1 information interface “BA Board.”

5.3.15 Maintain User Friendly Visual Appearance

Shneiderman et al. (2009) explain the importance of adopting a familiar visual appearance for the user interfaces. In their information display guidelines, Smith and Moiser (1986) also mentioned the importance of developing information displays in a format very much familiar to the end-users. It was identified that most of the current systems used by the firefighters in the UK runs on the Microsoft Windows Platform. Thus, it is decided to maintain the appearance of all the interfaces proposed as closer as possible to the visual appearance of Microsoft Windows-based application. Windows User Experience Interaction Guidelines for Vista (MSDN, 2009) are adopted throughout during the design of basic components of the user interfaces. This includes the design guidance for the components: Window Frame, Buttons, Menus, Progress Bars, Check Boxes, Drop-down Lists, Tabs, Sliders, Text boxes and Tree Views.

5.3.16 Avoid Use of Colours as the Only Means of Visual Information

According to the Shneiderman et al.'s (2009) guideline for the use of colours in the interface design, colour should not be used as the only visual means of conveying information, indicating an action, prompting a response or distinguishing a visual element. However, as identified under the contextual considerations, it is evident that UK FRS seems to ignore the implications due to colour blindness when presenting information for firefighters, despite the possibility of having operative firefighters with some form of a colour blindness. Therefore, there is a risk that some of the commonly used colours in the FRS such as red and green to have a direct impact on the officers suffering from colour blindness. As shown in Figure 5.25, such personnel may not recognize red and green as two different colours (Few, 2006).

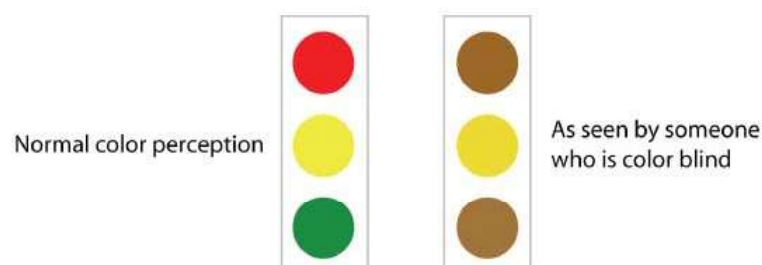


Figure 5.25: Colours Seen by a Normal and Colour Blind Person

Hence, there is a dilemma as to what extent colours should be used in the interfaces; whether to use it to its full potential considering lower colour blind percentages or to use it

with caution to minimize failures due to colour blindness? Having considered the fact that the most brigades of the UK FRS already use colours to a greater extent and have a very small percentage of colour blind officers, it is decided to maintain a similar level of use in the development of the interfaces proposed. However, as recommended by Shneiderman et al. (2009) it is decided not to use colours as the only mode to deliver meaning during the development of interfaces. Instead, colour with text and other means of graphics such as “Progress Bar” are combined to present information. The combination of colour with other modes such as text is expected to reduce the interpretation failures due to colour blindness. Furthermore, a single hue with intensity variations from light to dark or pale to bright is encouraged rather than using different hues to differentiate them (Few, 2006). Such practice is preferred in the development process of the mock-up interfaces, as even a colour blind person may not have a problem of distinguishing the variations of the same hue. Moreover, the selection of colours, which deliver specific meaning, is based on the colour stereotype standards (Bergum and Bergum, 1981).

5.3.17 More Design Decisions for Display of Information

As recommended by Smith and Moiser (1986), it is decided to develop text based information displays in such a way that order of columns and sorting of rows can be easily changed by the users.

As recommended in most of the interface design guidelines (Smith and Moiser, 1986; Shneiderman et al., 2009; Endsley et al., 2003b) it is decided to maintain consistency in the use of various terminology, abbreviations, formats, colours and symbols across different interfaces developed for a single job role as well as interfaces developed for different job roles. For example, 1) all the icons used to symbolize various hazards and other contextual parameters are similar across all the job roles and 2) all the forms developed for resource request and management have a similar appearance and functionality. As recommended by Smith and Moiser (1986), it is decided to design all the interfaces in such a way that users may not require remembering information from one screen to use in another screen. This is achieved by deploying all the information onto Windows-based interfaces and any number of interfaces called at once can adjust their sizes automatically to fit into the physical form factor of the display device. Furthermore, users are given the option of adjusting the size of any of the individual display window as well as the size of the individual components embedded in a particular window.

5.3.18 Design Decisions to Facilitate Human Data Entry for Firefighters

Careful investigation of information needs identified in Chapter 4 reveals that to satisfy some of the needs, it is essential to provide appropriate means of data input for all four job roles. It would become impossible to develop a system for firefighters to have a better information output without providing appropriate interfaces to facilitate end-user data input. Thus, it is decided to introduce suitable data entry interfaces for the use of all the job roles. However, earlier identified contextual factors related to workload, work behaviour and freedom of movement of firefighters indicate the limited ability of firefighters to enter data onto a visual display. Therefore, it is decided to use the interface design guide for data input by Smith and Moiser (1986) appropriately to 1) maintain minimal data input actions and minimal memory loading, 2) maintain compatibility of data entry with data display and flexible user control, and 3) minimal interaction time and potential errors during the data entry.

Having considered various contextual constraints relevant to the data entry ability of different firefighter jobs, the following design decisions are made to meet the above specified data entry design specifications.

- Apart from the voice data to control the visual display, data entry into visual interfaces is avoided for BA Wearers during their frontline operations.

However, for other situations it is decided to propose appropriate data entry by application of some useful Direct Manipulation techniques (Shneiderman, 1983). With the support of these techniques, some tailor-made interface interaction methods are introduced for all the firefighter job roles to facilitate data entry as recommended by Smith and Moiser (1986).

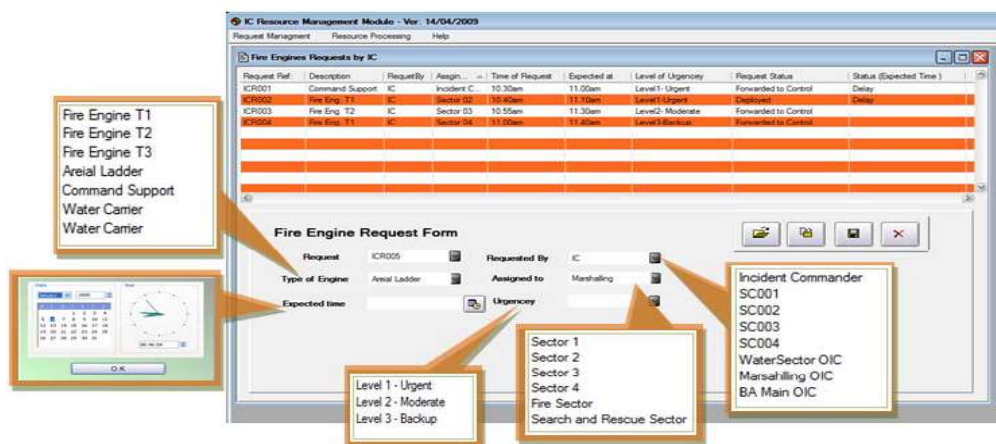


Figure 5.26: Data Input Form for Fire Engine Request

- It is decided to minimize the use of traditional type of data input forms for all the job roles. Forms are only proposed for SCs and the ICs to order and manage physical or human resources. Even in these forms, manual data entry is maintained at a minimum with the use of *Drop-down Option lists* and *Option Check Boxes*. For example, fire engine request from proposed for ICs and SCs is shown in Figure 5.26.
- Regardless of the firefighter job, they are given the option of introducing various types of hazards supported by a comprehensive set of hazard symbols (icons). With the use of *Drag and Drop* technique end-users will be able to add contextual hazard onto a display and position it at a location according to their preference. In a similar manner, firefighters could introduce items to be salvaged and new causalities onto the interfaces. The technique of *editable data displays* is introduced to enter data into the interfaces proposed to improve the basic perception related to various entities. Importantly, *Option lists* are appropriately introduced to minimize data to be manually keyed into these *editable displays*.



Figure 5.27: Editable Display to Enter Casualty Data



Figure 5.28: Option of Manually Keyed in Data for BAECO

For example, Figure 5.27 shows the editable display proposed to enter perception data related to casualty. As shown, this interface consists of several *Drop-down Option Lists* so the user can choose from the available options and minimize manually keyed in data. However, these interfaces also allow the option of users to manually key in the data with the use of appropriate key in device.

- In a rare situation where firefighters have to manually key in some information, it is decided to introduce three options depending on the appropriate technology for a particular job. These three options are to use 1) a manual key board, 2) a touch screen

based key pad and 3) use their own handwriting with the support of a “stylus”. For example, as shown in Figure 5.28, having considered relevant contextual factors, BAECO are proposed with an option where time to time they can manually key in their own comments related to ongoing BA operations either with a stylus or on screen keypad.

- It is decided to provide firefighters with several *Option Lists* to update the working status of the individual equipment manually so that they can input a change in the working order of various important resources and equipment located inside and outside the premises (Hydrants, Riser Inlets/outlets). This can be carried out by clicking on the appropriate icon representing a particular resource.
- It is decided to introduce the “Drawing Tool Box” consisting of several user friendly drawing tools to facilitate data entry needs in the form of graphical elements such as lines, circles and squares to designate sectors and cordons.

Details of some tailor-made high-level data manipulation proposed for flexible data entry will be discussed in the following section in relation to the functionality of data input displays. Subsequently, the feasibility of using the above explained design decisions are further discussed with the SMEs during the evaluation sessions of the mock-up interfaces. As explained in Chapter 6, findings of such evaluations led to the recommendations for further improvement of the information delivery and presentation for firefighters.

5.4 Mock-up Interfaces Proposed and their Features and Functionality

As described in Chapter 3, Windows-based software prototyping tools, GUI Design Studio Ver. 2 and Adobe Flash are used for the design and development of the mock-up interfaces proposed. This process is also supported by the 1) Google maps, 2) two dimensional building plans of a hypothetical building premises and 3) freely downloadable fire emergency related icons and symbols. The proposed mock-ups will form the basis of the first step of an evolutionary development program of an fully-fledged IS supporting firefighters during their response. These mock-up interfaces are primarily capable of showing the static situations of a dynamic and moving incident and therefore may not display the high-level of functionality seen in fully fledged working prototype capable of simulating the functionality of the final product. However, where essential, effort is made to embed necessary dynamism to the mock-up interfaces so end-users could experience the look and feel of the actual information system. Interfaces simulating the movement of fire

fighters in a building, data entry interfaces embedded with direct manipulation and dynamically appearing alarms are several instances where some high-level functionality is introduced with the support of Adobe flash software prototyping tool.

Adhering to the specific design decisions explained in the previous section, efforts are made to develop four software mock-ups consisting of human computer interfaces relevant to the job roles: IC, SC, BAECO and BA Wearer (Yang et al., 2009b; 2009c). These mock-ups are expected to present the information needs of each job role appropriately. The mock-ups proposed consist of several categories of information output interfaces. These include interfaces capable of presenting:

- Perception information related to both the internal (inside the incident premise) and external context (outside the incident premise) of the incident to provide relevant global overview of the incident.
- Perception information related to one or few specific contextual parameters or elements located outside the incident premise.
- Perception information related to one or few specific contextual parameters or elements located inside the incident premise.
- Comprehension information related to the external context.
- Comprehension information related to the internal context.
- Projection information related to the internal context.
- Projection information related to the external context.
- Alarms/Alerts

At any given moment of time, depending on their individual requirements firefighters will be able to obtain the support of either one or several of the above described categories of interfaces. In addition to these categories, there are also some other interfaces, which are unique and difficult to categorize. For example, the “Black Box” is one of such interfaces. This particular interface is capable of recalling the past data supporting ICs to achieve the goal “*Ensure Post Incident Considerations.*” Apart from the information output interfaces, mock-ups proposed also consist of appropriate interfaces for Data/Information Input.

To understand the capability and the capacity of the IS proposed, it is considered as important to explain the in-depth features and functionality of the mock-up interfaces. Features and functionality of some of the important interfaces proposed are already explained in the section of design decisions. This includes the “Dash Board” interface

developed to enhance the incident wide Perception level SA of ICs and several other interfaces supporting both ICs and SCs to enhance their comprehension and projection level SA related to the External and Internal context of the incident. In addition to those already explained, nearly 350 different information layers and interfaces are proposed for the use of four firefighter job roles, and it is impractical and difficult to explain the features and functionality of each of the interfaces comprehensively. Therefore, it is decided to select several important interfaces and explain their features and functionality so that such explanations will provide an overview and the flavour of the interfaces proposed. The interfaces selected include both information output and input interfaces developed for the job roles: IC, BAECO and BA Wearer. Since the functionality of most of the interfaces proposed for the job role SC is similar to the interfaces of an IC, only IC interfaces are selected for this discussion. In addition, some of the remaining significant interfaces are shown in Appendix 5.2.

5.4.1 Interfaces to Enhance SA related to External Context of the Incident

Figure 5.29 shows the snap shot of the interface developed to present the Level 2 comprehension information requirements of an IC related to the outside of a building on fire. By default, it displays the geographical map layer with the incident location. With the use of *Button 2*, the end-user will be able to magnify the displayed information *in* and *out* and panning *left*, *right*, *up* and *down*. In addition, the user has the alternative of using the mouse buttons for zooming and panning.

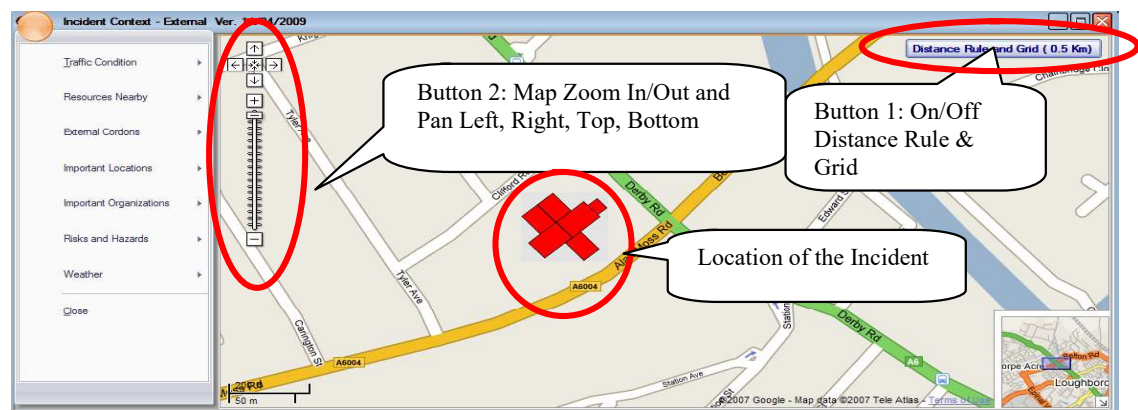


Figure 5.29: Interface to Present External Context of an Incident for an IC

As shown in Figure 5.30, *Button 1* allows the user to call the layer of *Distance Rule & Grid* onto the map to provide distance information from the centre of the incident to a particular location outside the incident. This interface is developed in such a way that the end-user is provided with the facility of calling various Level 2 information layers, so that the user can

enhance their comprehension on various contextual parameters externally located to the incident premise. Furthermore, it provides flexible access to the interfaces containing Level 3 projection information related to the external context to further enhance end-user SA.

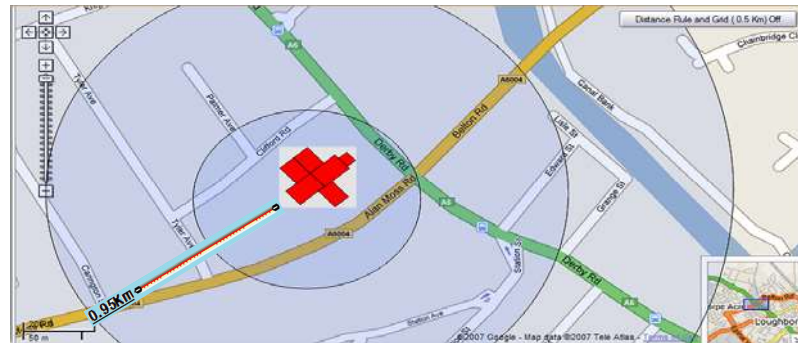


Figure 5.30: Distance Rule & Grid Provides the Distance Information

Traffic related information needs identified for IC are considered as an example to explain the functionality and features of the interfaces capable of displaying comprehension and projection information related to the external context of an incident.

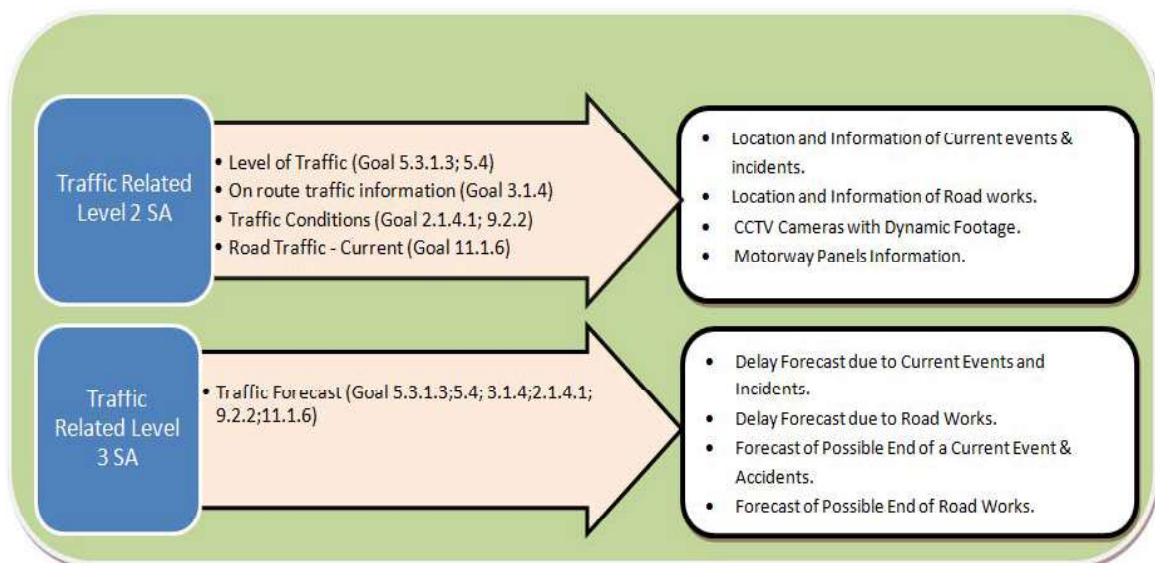


Figure 5.31: Traffic Related Level 2 and Level 3 Information Needs of ICs

Figure 5.31 shows each and every previously elicited Level 2 and Level 3 traffic related information needs of an IC to be displayed via this particular interface. Several different goals of an IC require similar Level 2 and Level 3 information needs to enhance their traffic related SA. Therefore, whenever an IC wants to achieve a goal, which needs to enhance the traffic related SA, the human computer interfaces proposed should be able to organise these Level 2 and Level 3 information. This interface proposes to use four main pieces of information: 1) Location of Current Events & Incidents, 2) Roadworks, 3) CCTV footage and 4) Motorway panel information to enhance the Level 2 traffic related SA of ICs.

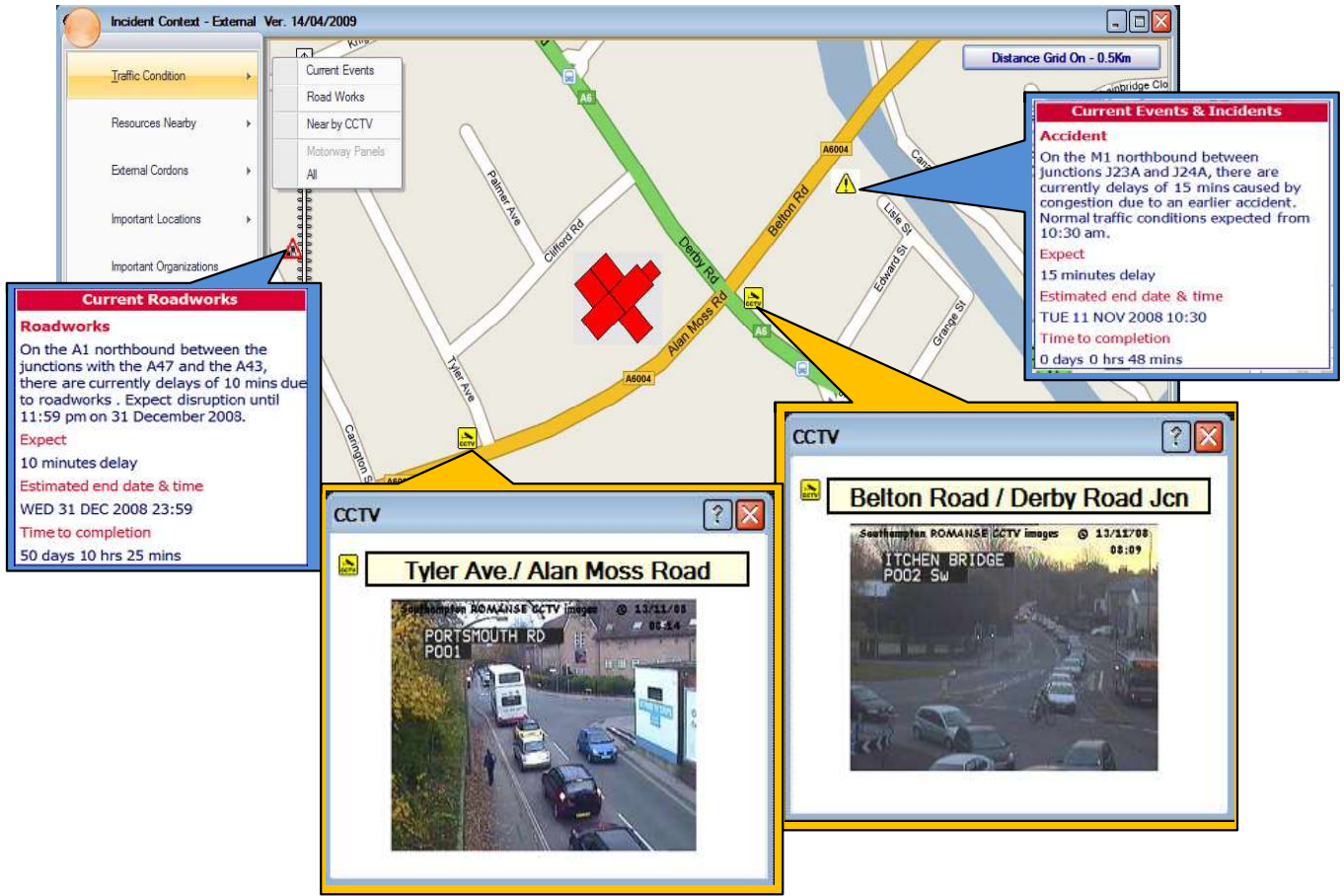


Figure 5.32: Presentation of Traffic Information

As shown in Figure 5.32, *Location of Current Events & Incidents* and *Roadworks* are displayed via appropriate symbols positioned on the map. In addition, by pointing to any CCTV symbol end-user will be able to obtain a dynamic footage of vehicle traffic along a particular road to raise their Level 2 SA. In addition, as shown in Figure 5.33, to further enhance their level 2 SA, an IC will be able to call information captured from the motorway panels by pointing to the relevant motorway panel symbol.

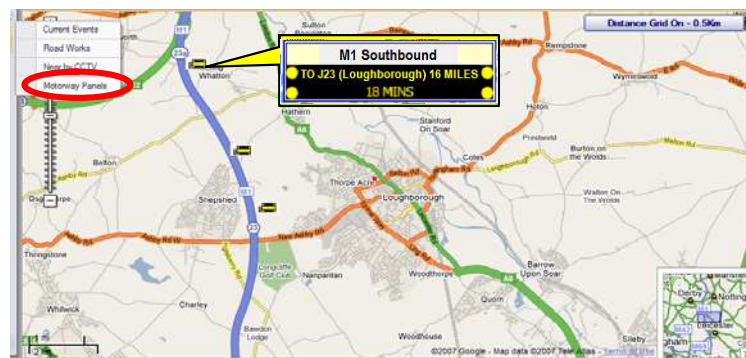


Figure 5.33: Dynamic Information on the Motorway Panels

Furthermore, as shown in Figure 5.32, by pointing to the symbols representing “Current Events & Incidents” shown on this interface, the end-user will be able to call additional interfaces presenting Level 3 Projection information such as forecasted delay and expected end time of each event with further details of the unexpected accident or incident. Similarly, pointing to the “Current Roadworks” symbol will display the details of planned roadworks along a particular road and delays expected. In addition, motorway panel information is also capable of providing some Level 3 information related to forecasted delays in the motorways (Figure 5.34).

Similar type of interfaces are proposed for other job roles to obtain traffic related Level 2 and Level 3 information needs by combining some common or/and unique layers of traffic related information. The above example shows the possibility of enhancing external contextual SA of an IC only in relation to a single source of information: *Traffic*. In addition, end-users are provided with the opportunity of mixing a range of various information layers belonging to any other single source of information source or many information sources to enhance their SA on external context of an incident at any given moment of their response work.

5.4.2 The “BA Board” Interface

The interface proposed to represent the BA entry control board, “BA Board” organises information in a summarised manner to show a high-level overview of the situation around the goals of BAECO. While enhancing the global overview related to the goals of a BAECO, it also provides rapid access to many other interfaces to enhance SA to higher levels of comprehension and projection. As shown in Figure 5.34, this interface can display a summary of some important information related to individual firefighters dispatched by a particular BA Board (Figure 5.34). This information is identified as very important for the work of BAECO. Particularly, the information requirements elicited under the sub goals of the goal: *Ensure Safety, Health, and Welfare of Deployed BA Wearers* has shown the keenness of the BAECO to know the level of air remaining and the duration of which the firefighter would be able to use the air available. One important air related piece of information is called “Time of Whistle.” With this, BAECO will be able to figure out the time available for a BA Wearer before air pressure of his/her cylinder reaches a predefined safety level.

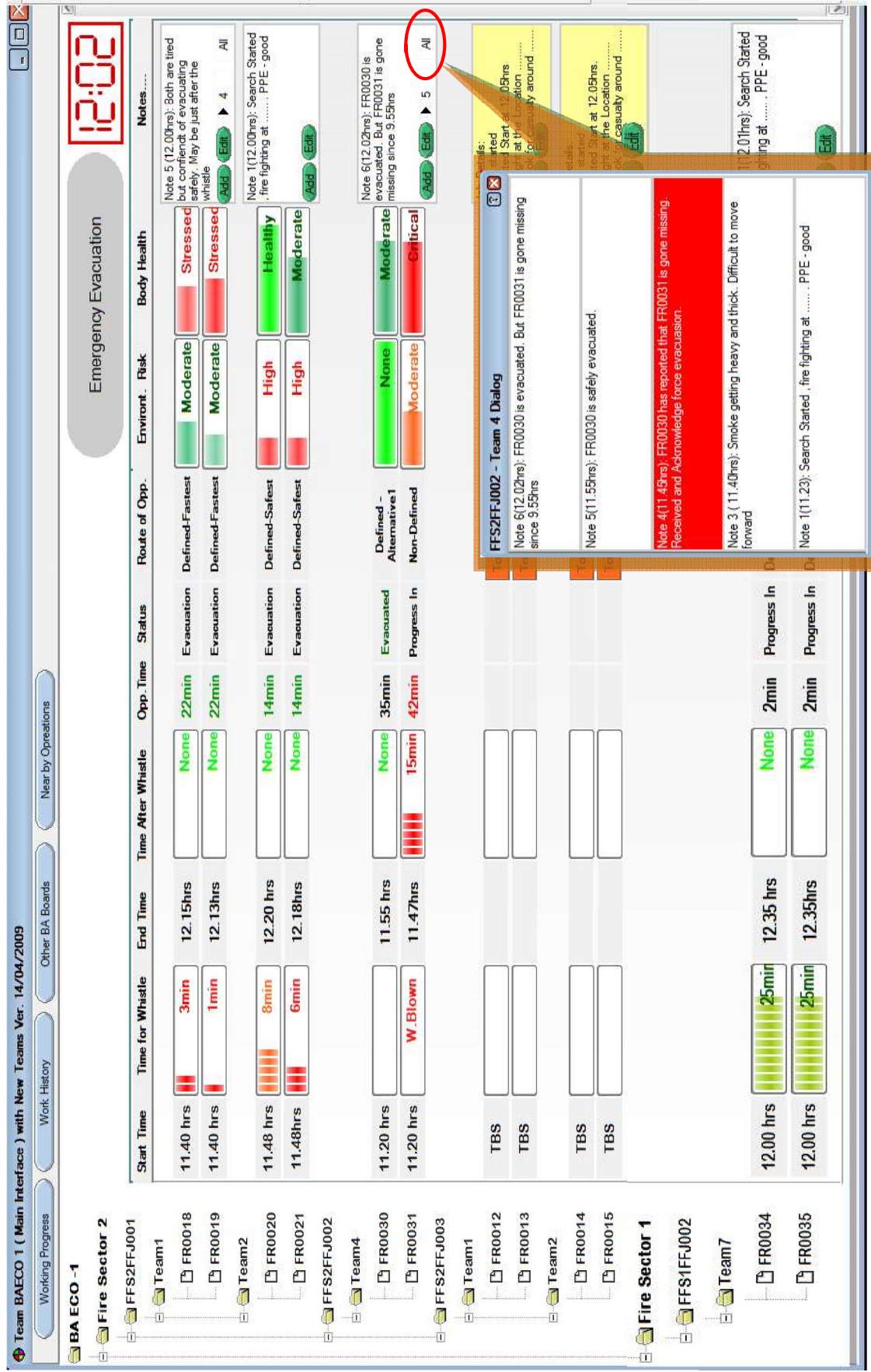


Figure 5.34: The “BA Board” Interface

| Pressure Bar | 1800 Litres | 3600 Litres |
|--------------|-------------|-------------|
| | (minutes) | |
| 200 | 35 | 70 |
| 190 | 33 | 66 |
| 180 | 30 | 60 |
| 170 | 28 | 56 |
| 160 | 26 | 52 |
| 150 | 23 | 46 |
| 140 | 21 | 42 |
| 130 | 19 | 38 |
| 120 | 17 | 34 |
| 110 | 14 | 28 |
| 100 | 12 | 24 |

HARD WORK MAY REDUCE DURATION

Figure 5.35: Chart that Support the Calculation of “Time of Whistle”

Traditionally most of the BA boards in use need a BAECO to calculate and update the “Time of Whistle” manually. This manual calculation is made with the use of a chart attached to the BA Board indicating a relationship between remaining air pressure and the available minutes of air (Figure 5.35). However, during actual BA operations, “Time of Whistle” may become a dynamic figure depending on the rate of breathing of an individual firefighter. As a result, this manually entered figure could often become inaccurate. More recently, semi- automated telemetry BA board such as Drager Merlin (Figure 5.36) has incorporated a dynamically updated “Time of Whistle.”

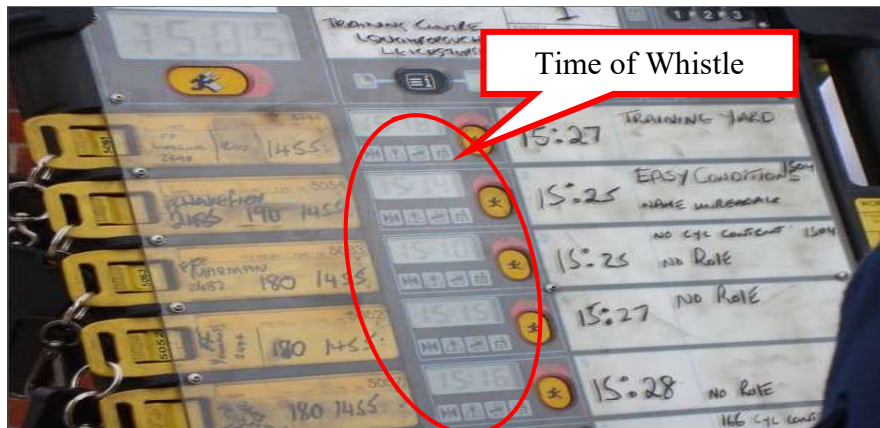


Figure 5.36: New Semi- Automated BA Boards with Dynamic Time of Whistle

The BA board proposed could display the duration remaining till the “Time of Whistle” rather than the actual “Time of Whistle.” This is dynamically displayed via a symbol comprising both a graphical and a numerical scale. During the requirement elicitation, most of the interviewed BAECOs preferred a dynamically counting down clock showing the remaining minutes till the “Time of Whistle.” At present, BAECOs find it difficult as they

always have to calculate the countdown with the use of the clock attached to the BA Board. In addition, the interface also proposes to show the time a firefighter has spent in the hazard zone after the “Time of Whistle.” This particular indicator is only relevant for the firefighters who have not evacuated before reaching their “Time of Whistle.” Furthermore, the data under the heading of “End Time” is capable of providing the BAECO the time till the air cylinder become empty for each and every firefighter deployed. Dynamic use of breathing and remaining level of air is used to calculate the “End Time.”

The participants of GDIA process indicated that as a BAECO, it is very difficult for them to figure out the health of the deployed crews by processing several pieces of separate information such as body temperature, heart and breathing rate, context of the immediate surroundings, recent work patterns and individual health profile of a particular BA wearer. However, most of them indicated the importance of having an indicator of estimated health of the deployed BA wearers. They believe that such an indicator could help them to improve the overall health and safety of deployed crews.

Interviewee 11 (Participant of Decision and Information Requirements Capturing Interviews for BAECO job role): it will be a very difficult judgment for us As a BAECO to decide whether BAs are in good health. We can't simply decide this based on the body temperature or heart rate. ... We may need many other pieces of information.... like surrounding context info, BA's medical profile, how many hours they have worked during past few days, etc, etc..... As you know, this information is not available at our fingertips... that is one reason..... and even if we have these information, with our all other work it will be very difficult to decide the fitness of each fire fighter. But...But....if somebody or something can collect this information and tell us with some level of accuracy about their overall health that is wonderful.....

Interviewee 2 – BAECO (Participant of Validation of Decision and Information Requirements for BAECO job role):.....We really like to know whether BAs are in trouble before they on their own realize that..... this is important ... when BAs realize they are in trouble it may be too late for us to save them... so if we know their levels of fitness continuously it will be very useful....

However, as described below, currently BA Wearers are given the responsibility of judging their own health and fitness.

Interviewee 13 BAECO (Participant of Validation of Decision and Information Requirements for BAECO job role):*We do not have enough information to judge the health of deployed BAs, on their own they should be able to do it much better.....*

Interviewee 2 – BAECO (Participant of Validation of Decision and Information Requirements for BAECO job role):..... *But unfortunately, it is impossible for us... so only possible way now is to ask BAs to look after their own fitness.....*

Based on this specific requirement, this interface is proposed to display the indicator “Body Health.” With the use of coloured progress bar in combination with text, this particular indicator proposes to display the overall health of each BA Wearer deployed continuously. This interface also proposes a similar indicator “Environmental Risk,” generated by the contextual conditions around each BA Wearer deployed to display the overall risk level dynamically. In addition to these indicators, BAECOs will also have access to a secondary interface, displaying the movement of firefighters either individually or as a team assigned to a particular job or a sector. This particular interface also allows the end-user to drill down as and when necessary to obtain more detailed information related to vital signs and several other useful profile information of each BA Wearer.

5.4.3 The “Guideline” Interface

As shown in Figure 5.37, “Guideline” interface proposes to provide a 3D visual of the front view of the firefighters, guiding them *to* and *from* a predefined destination. This particular interface is capable of enhancing their SA from start to the end of a BA operation. The development of this particular type of interface is motivated by the contextual implications due to the use of physical guidelines.

This interface is capable of providing information such as *defined route to the destination, distance to the destination* and *the nearest turns and exits expected along the route*. Furthermore, as shown in Figure 5.37, with the use of simple voice commands BA Wearers are able to view the contextual profiles such as temperature and smoke beyond the doors located along their path. As a default feature, this interface proposes to display the overall body health of the firefighter with the use of a coloured progress bar combined with text.

In addition, with the use of the “Health Monitor” option, the BA Wearer will be able to access a display of graphical indicators showing some details of their own body health including remaining air content.



Figure 5.37: The “Guideline” Interface

This interface is capable of indicating the required changes to the predefined path based on the contextual information captured, so that safety of the BA Wearer during navigation can be continuously maintained. It is proposed that with a simple voice command, the end-user can switch their view from the default “My View” tab of the interface to the tab displaying “Map View.” The “Map View” provides the current location and the intended location of the destination of a BA Wearer. With a simple voice command, BA Wearers will be able to call other additional information layers such as *Contextual Hazard Profile of the area*, *Defined route to the destination*, *Location of fellow BA team members*, *Available installation and equipments around the area*.

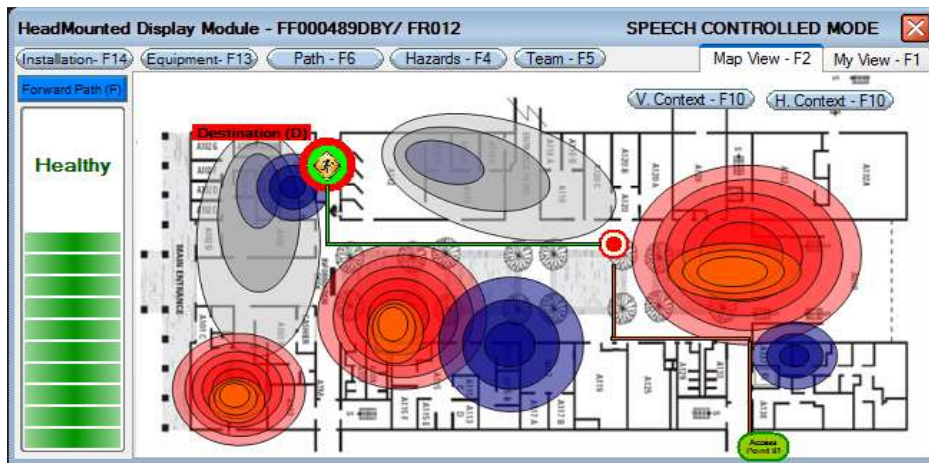


Figure 5.38: Proposed Display for the “Map View” with Superimposed Layers of Additional Information

As an example, Figure 5.38 shows a display, which has superimposed the additional information layers of *defined route of the BA Wearer* with the prevailing *contextual hazard profile* onto the “Map View” interface. This information will significantly enhance the SA of a moving BA wearer.

For this interface, it is proposed to provide information in the form of voice instructions until BA wearer decides he/she needs more comprehensive display of information via the visual interface. The idea is that the BA Wearer will be able to activate his/her visual display by giving a simple voice command requesting it to *wake up*. Until such time, the visual display will be in the *sleep* mode. The technical feasibility of this proposal will be further discussed at the mock-up demonstration.

5.4.4 The “Black Box” Interface

In Chapter 4, the Goal: “*Ensure Post Incident Considerations*” was identified as one of the top-level goals of an IC. However, different from other top-level goals this particular goal is related to the issues which need FRS involvement after the emergency phase. Examples include the following:

- Post-mortem enquiries and coroner's hearings
- Fire investigation
- Accident investigation (where a death has or may result then the ‘Work Related Death Protocol’ must be adhered to)
- Public or judicial enquiries

- Mitigation
- Financial costs to the brigade i.e. damaged equipment
- Criminal Investigation
- Incident debriefing and evaluation
- Fire safety issues
- Learning and recommendations, both local and national
- Critical incident – ongoing emotional and welfare support

The success of carrying out the post incident activities is related to the success of the IC in identifying what the post incident considerations might be (Fire Service Manual Volume 2: Incident Command, 2008). The level of assessing the post incident considerations often depends on the ability of an IC to answer questions such as:

- *What happened during critical search and rescue/fire fighting operations (caused deaths/near deaths /BA emergency)?*
- *Is there any breach in legislation during operation?*
- *Was building performed as expected?*
- *Was there any threat to the safety of the crews?*

The GDI diagram developed in Chapter 4 for the goal “*Ensure Post Incident Considerations*” showed the importance of acquiring information that enhances the SA of the IC so that they can answer these questions successfully. However, as explained in the contextual considerations, it is a challenge and added burden for the IC during an incident to maintain and organise such information in a meaningful manner so that it can be reused after the incident during various debriefing and investigation sessions.

To support an IC to reach the goal “*Ensure Post Incident Considerations*” successfully, while minimizing their involvement, a conceptual interface “Black Box” is proposed. This interface will minimize the time and the efforts of ICs to carry out work related to the post incident considerations and therefore, allow more effort and commitment to other crucial activities during an incident. This particular interface is capable of replaying or recalling the events already occurred. It allows the end-user to recall snapshots of any number of interfaces on to a display device. For example, as shown in Figure 5.39, an IC would be able to recall snapshots of three important interfaces: External SA and Internal SA of the 6th Floor, “Dash Board” and “BA Board,” which deployed the BA Wearers into the 6th floor.

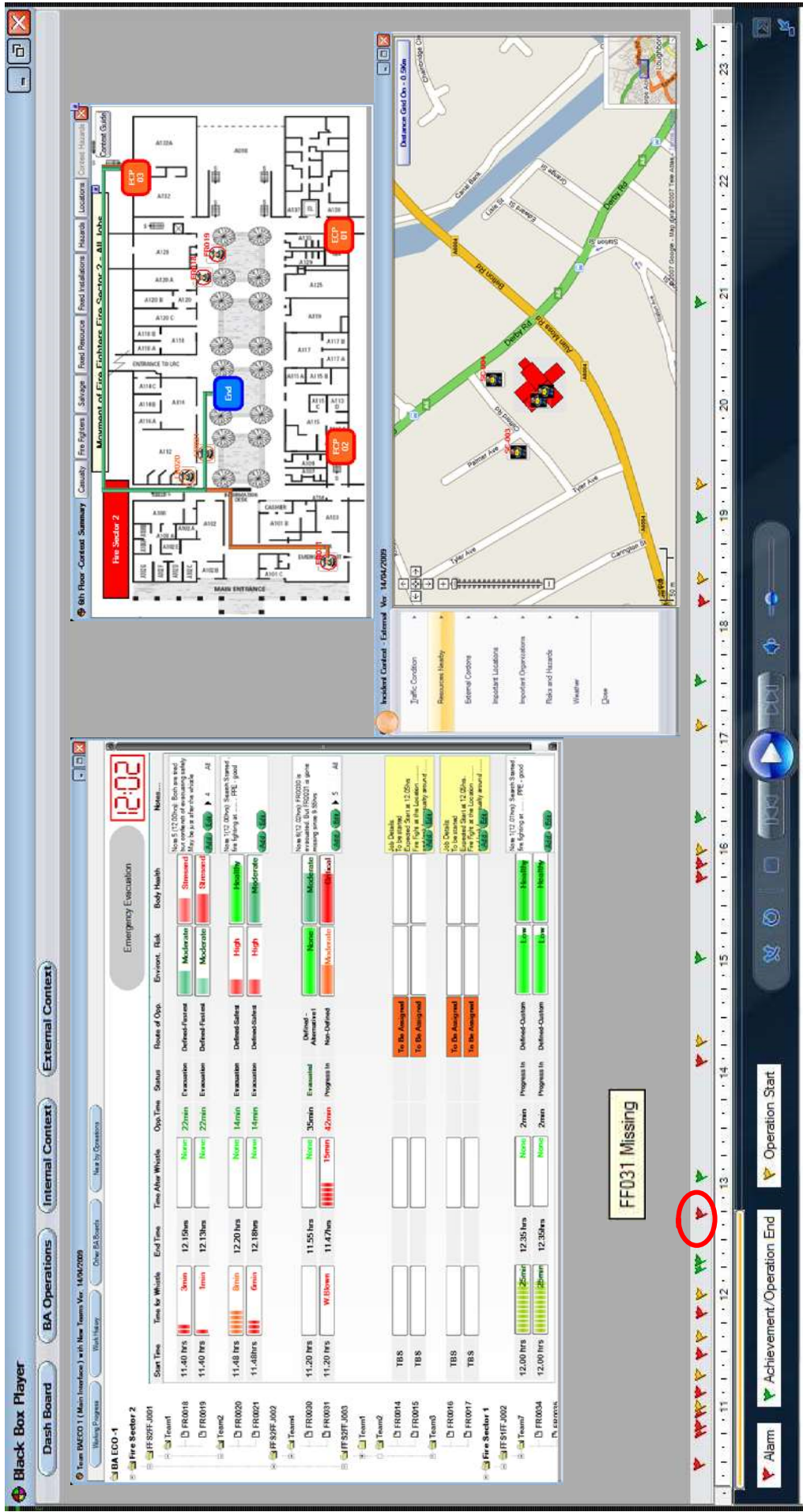


Figure 5.39: The “Black Box” Interface

This interface captures the important instances of an incident at a selected time and flags them. Later, by clicking on a flagged event, the end-user will be able to recall any of the interfaces displaying the situation of the incident at that particular time. Furthermore, the end-user will have the option of playing back these instances along a time line. Therefore, by selecting a flagged instance or by playing back along a time scale, the end-user would be able to recall appropriate interfaces related to a post incident activity.

5.4.5 Interfaces to Support Fire and Rescue Officers in a Moving Fire Engine

This particular interface is exclusively designed for the firefighters deployed in a moving fire engine to an incident, which has already progressed to the extent that a proper incident command hierarchy is already formed. These officers are most likely to perform the jobs: BAECO and BA Wearer. This interface is proposed to be deployed onto the mobile data terminals fixed inside the fire engines (Figure 5.40). Even before they arrive at the incident, using this particular interface, it is possible for the officers to know which particular sector they are allocated to. This is possible as the interface “Fire Engine Request Form” is capable of capturing the sector for which a particular request for a fire engine is made. With this interface, the firefighters are expected to increase their SA about what is happening in the sector they expect to work in. As shown in Figure 5.41, in this particular example, Fire engine is assigned to the “Fire Sector 2” and expected arrival time at the incident is 5min. By clicking on the button “Internal Context - Fire Sector 2,” firefighters will be able to call a display showing the internal context of the “Fire Sector 2.”

This interface also provides the option of accessing several other interfaces useful to enhance the SA of firefighters who are on-route to the incident. For example, with the use of the “External Context” button, the end-users are given the opportunity of calling up a variety of additional information capable of showing what is happening externally to the incident building. In addition, by clicking the button “BAECO1-Fire Sector 2” they will be able to call the display of BA entry control board, which contains current information of the BA operations in that particular sector. In addition, “Overall Incident Summary” would display the summarised contextual information related to the overall incident.



Figure 5.40: Interface Supporting Fire Fighters on the Move

A different interface is proposed for the officers deployed in fire engines attending before a command hierarchy is formed and therefore, it is impossible to know the area of operations.

A customized version of the above explained interface is proposed for all the senior officers, usually deployed in a mode of transport different to a fire engine. This particular interface is feasible to deploy into any other form of a mobile display, such as a rugged laptop carried inside the vehicle of a senior fire officer. These customized interfaces are expected to become useful for the job roles of SC and IC who are on the way to the incident.

5.4.6 Interfaces to Display Alarms for an IC

At present, an incident is often managed by a formal hierarchy of having several layers with the span of control of an IC set to a maximum of five (Fire Service Manual Volume 2: Incident Command, 2008). One of the main reasons for such rigid hierarchy is to avoid an IC being overloaded with unnecessary information. It allows ICs only to access the filtered information that increases his/her global SA. At present, filtered information that needs the IC's attention is received in the form of direct or indirect verbal radio messages. To overcome the limited capability of voice alerts, it is proposed to include visual alarms. These would be generated by the system to help ICs to know when problems arise and need immediate attention. Several prototypical alarms are proposed to enhance the global SA of an IC based on the guidelines provided to develop alarms for the operators of complex systems (Endsley et al., 2003b). These include alarms for:

- Sector Commander Reliefs
- Resource Request Management
- Request Delays
- Arrival of Delayed Resources
- Hazards and Emergencies
- BA Emergency
- Crew members gone missing and in a critical condition

To explain the functionality of the visual alarms, the alarm for *Sector Commander Reliefs* is discussed below. As shown in Figure 5.41, an IC will be alarmed visually whenever reliefs are due to be made in the top-level of the IC hierarchy.

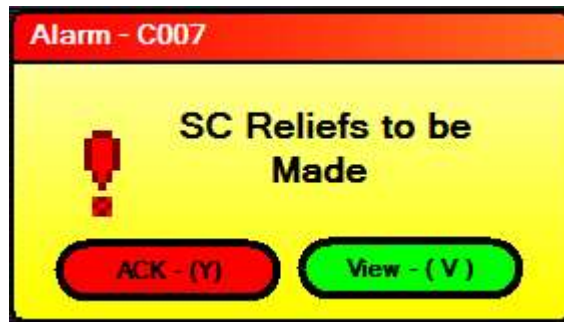


Figure 5.38: Alarm for Sector Commander Reliefs

By acknowledging (ACK), an IC can move this alarm to a serial list of alarms consisting of all the alarms classified under several categories. By clicking the *View* button, an IC would be directed to *Relief Management Form*, which is capable of highlighting the job roles that require reliefs. With the use of this form, IC will be able to assign the most appropriate reliefs. However, if an IC just ACK them, in a pre-specified period, IC will be alarmed again, requesting him to make the appropriate relief. It is proposed to repeat the alarms that specifically need some action of the end-user in predetermined intervals of time, assigned according to the preference of the end-user. Such alarms will be repeated until appropriate action is being taken.

Various categories of alarms are proposed to be displayed on a serial list of alarms (Endsley et al., 2003b), which can be accessed by an IC at any time. These alarms are proposed to be categorized in to three main categories:

- Resource Management
- Hazards & Emergencies
- The status of firefighters and casualties

Each alarm is logged and accumulated on to a serial list of alarms belonging to one of these categories. As shown in Figure 5.42, three serial lists representing the three categories of alarms are proposed to be developed with the use of an interface consisting of tab sheets. As shown, all the active alarms that need the attention of the IC are highlighted and displayed in bold letters. This effect will remain until the alarms get deactivated.

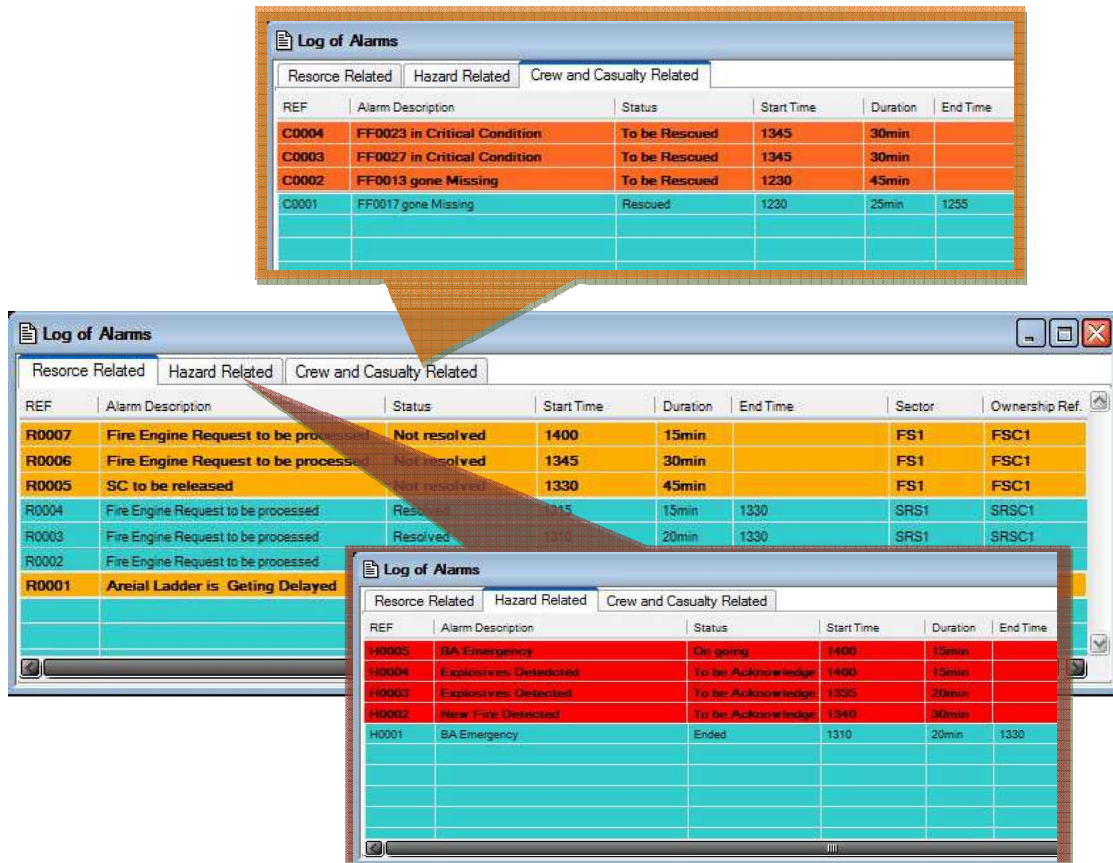


Figure 5.39: Interface Displaying the IC Alarm Log

It is important for SCs encountering a particular hazard in their territory to acknowledge the recognition of such hazards immediately. Therefore, the alarms, which indicate hazards such as explosives detected and new fire detected, should be acknowledged first by the respective SC. Until such time, those alarms would be highlighted as activated on the alarm log of the IC.



Figure 5.40: Interface Reminding the Hazard Need to be Acknowledged

Furthermore, as shown in Figure 5.43, time to time an IC will get a pop-up alarm on his display indicating that a particular hazard or hazards are not yet been acknowledged by the respective SC and therefore, need attention.

5.4.7 Interfaces to Display Alarms for a BA Wearer

To explain the functionality of the visual alarms proposed for BA Wearers, the alarms *Out of Path* and *Out of Sight* are selected. Assuming one firefighter is far away from his assigned route, at the outset this particular alarm is proposed to generate as a voice alarm. So it will deliver the alarm as a voice statement “*You are not in the correct path.*” Since the visual display proposed for a firefighter is expected to be in the *Sleep* mode as its default mode, system generated alarms are proposed to reach the end-user as a voice communiqué. After such voice communiqué, end-users would be able to obtain more elaborated information on that alarm with the use of the visual display by requesting it to switch its mode to *Wakeup*. In the *Wakeup* mode, end-user will be able to see the alarm visually as shown in Figure 5.44.



Figure 5.41: Visual Alert Pop up For BA wearer “Out of Route/Path”

Furthermore, with a simple voice command end-user will be able to acknowledge such alarm or call a layer of information providing his/her current location (Figure 5.45).

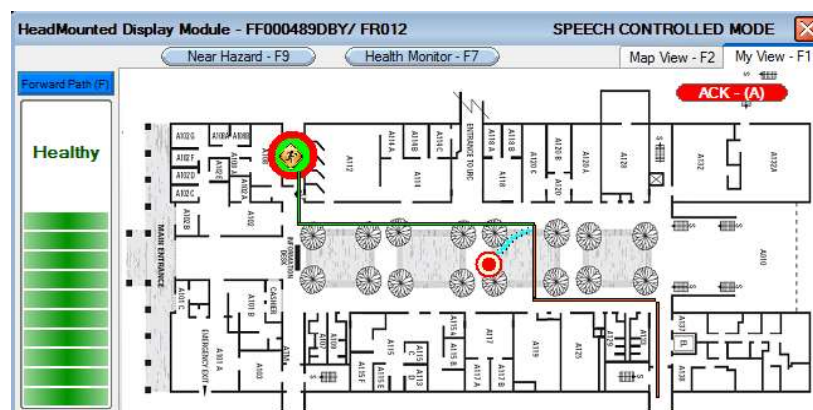


Figure 5.42: Proposed View Mode Interface for the “Out of Path” Alarm

This particular alarm is considered to be important as it enhances the performance of the “Guideline” interface. It will be useful to avoid any physical attachment to a guideline, yet support firefighters to maintain their movement along the required route.

As shown in Figure 5.46, it is also proposed to have the alarm: *Out of sight/range*, which generates an alert when the distance between two firefighters exceeds the predetermined safety distance.

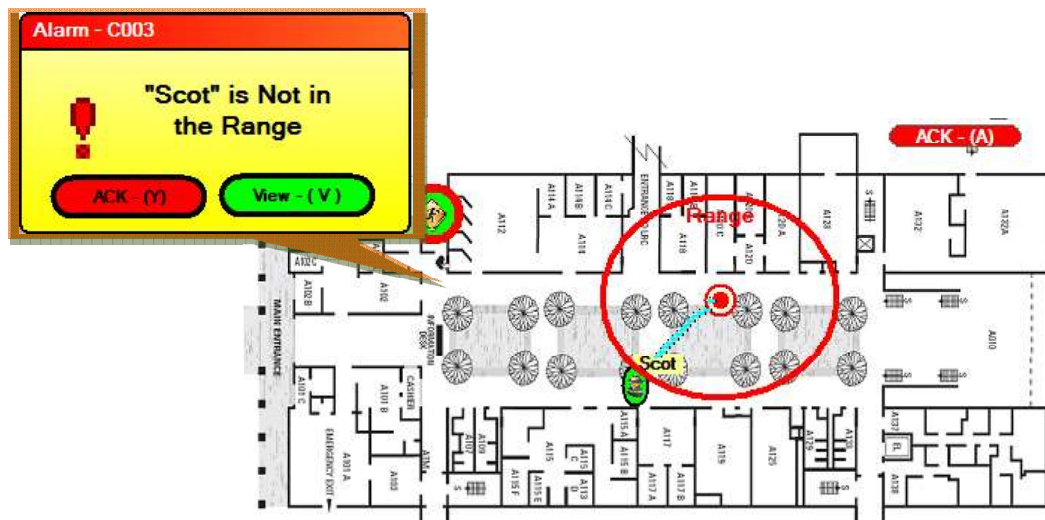


Figure 5.43: Proposed View Mode Interface for the “Out of Sight/Range” Alarm

Importantly, while maintaining the recommended safe distance between team members throughout their operations, this alarm allows BA wearers to minimize their movement restrictions due to the “Personal Line,” which maintain a physical link between two firefighters. Some of the other important alarms proposed are as follows:

- BA Emergency Alerts for BAECO and BA Wearer.
- Critical Air Level alerts for BAECO and BA Wearer.
- BA Evacuation Alerts for BAECO.
- Alerts to indicate new hazards in the path of operations for SC, BAECO and BA Wearer.
- Body Health Alerts for BAECO and BA Wearer.

5.4.8 Interfaces to Input Data for an IC

As explained earlier, it is decided to develop appropriate data input interfaces for all the job roles. Specifically, for an IC, there are proposed input interfaces, which cover the data input in *Sector Management*, *Fire Ground Job Management* and *Fire Ground Resource*

Management. Data input interfaces proposed for the SC are similar to those of IC, but focus on the data input relevant to a particular sector. As explained in the design decisions, these data input interfaces are supported by some tailor- made data manipulation to interact with the interface during data input. Data input interface proposed for Sector management is selected to explain the features of some of the high-level data manipulation techniques when interact with the data input interfaces.

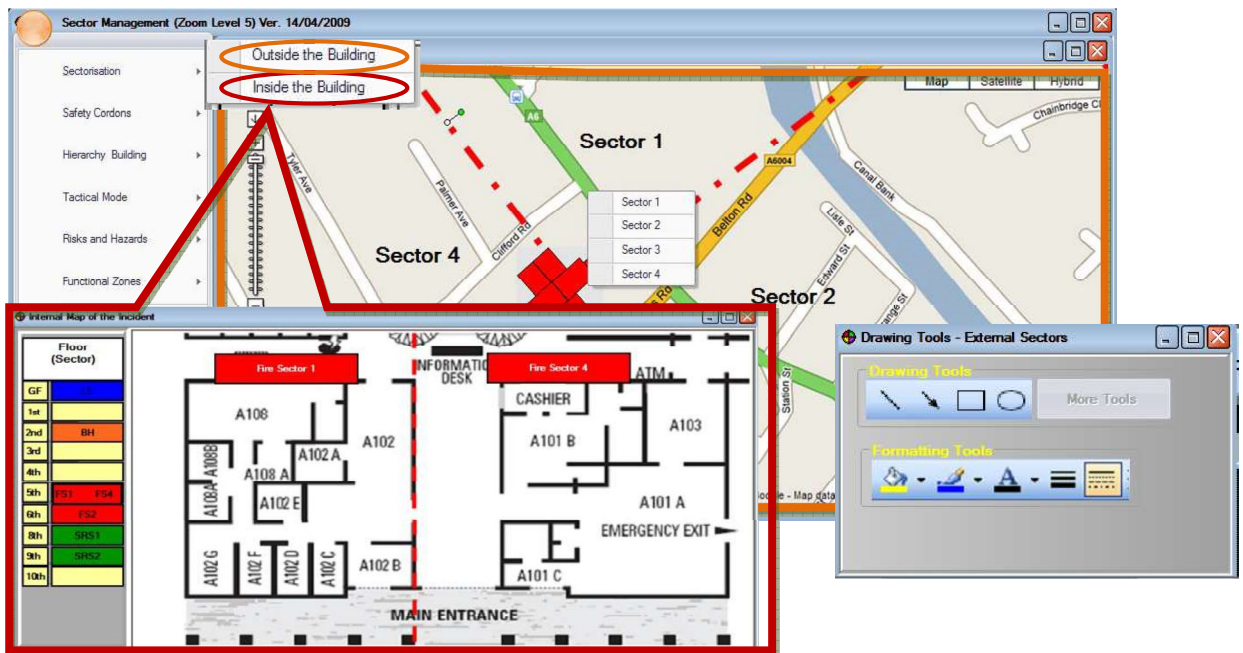


Figure 5.44: Display of Internal and External Sectorisation

As shown in Figure 5.47, a “Drawing Toolbox” supports the sectorisation process during an incident for both the external and the internal environments of the incident. With the use of simple drawing tools: lines, arrows, boxes, ellipses and free hand line drawing facility of the toolbox, an IC will be able to sectorise the external environment by providing a number to each sector. Similarly, an IC will be able to sectorise the internal areas appropriately by defining them as the lobby sector, fire sector, search and rescue sector or bridgehead. Furthermore, this interface is designed in such a way that at the end of naming each sector, it prompts the end-user with a choice of tactical modes to be selected for each sector. Similarly, as shown in Figure 5.48, the end-user will be able to define and name various safety cordons around the incident with the support of the “Drawing Toolbox.” In the process of sectorisation and creating appropriate safety cordons, the end-user is given the option of using the *Distance Rule and Grid* to improve the precision of the measurements and the sizes of both sectors and cordons.

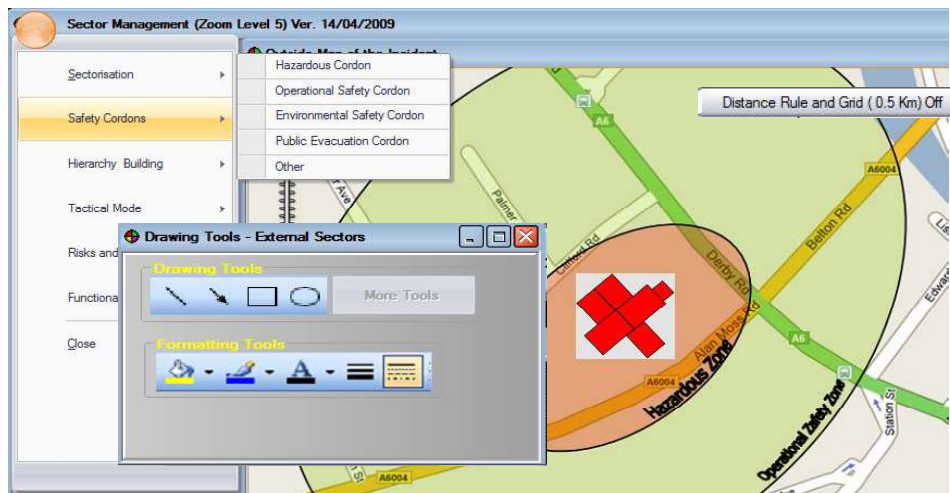


Figure 5.48: Display for the Development of Safety Cordons

5.4.9 Interfaces to Input Data for a BAECO

There are several useful data input interfaces proposed for the use of BAECO. This includes interfaces for the management of BA Teams, BA Wearer Routing and management of BA emergency and evacuation. Among these interfaces, the “Route Planner” interface is significant as the functionality of the “Guideline” interface proposed for the BA Wearer navigation is primarily driven by the route planned with the use of this interface. Traditionally, BA navigation entirely depends on the support of the guidelines. Instead, the proposed “Route Planner” interface allows BAECOs to plan a route for each and every BA operation (Figure 5.49). This interface is capable of laying a computerized virtual guideline. At first, “Route planner” will request the BAECO to provide the start and end location of an intended BA operation. In addition, it will request the BAECO to input appropriate *access points* and *entry control points* as the transit locations. Thereafter considering the existing risks, hazards and existing paths, this interface will be able to forecast the options of safest path and quickest path to the desired destination. The end-user would then be able to select the best path according to his/her preference. Furthermore, the interface allows the end-user an option of defining a customized route on his/her own. With this option, the end-user would be able to draw and digitize a route on his/her own for a BA operation, using the support of “Drawing Toolbox.” Such planned routes would take account of the prevailing conditions at the incident, and will become the navigational input for the BA wearers who carry out various BA operations.

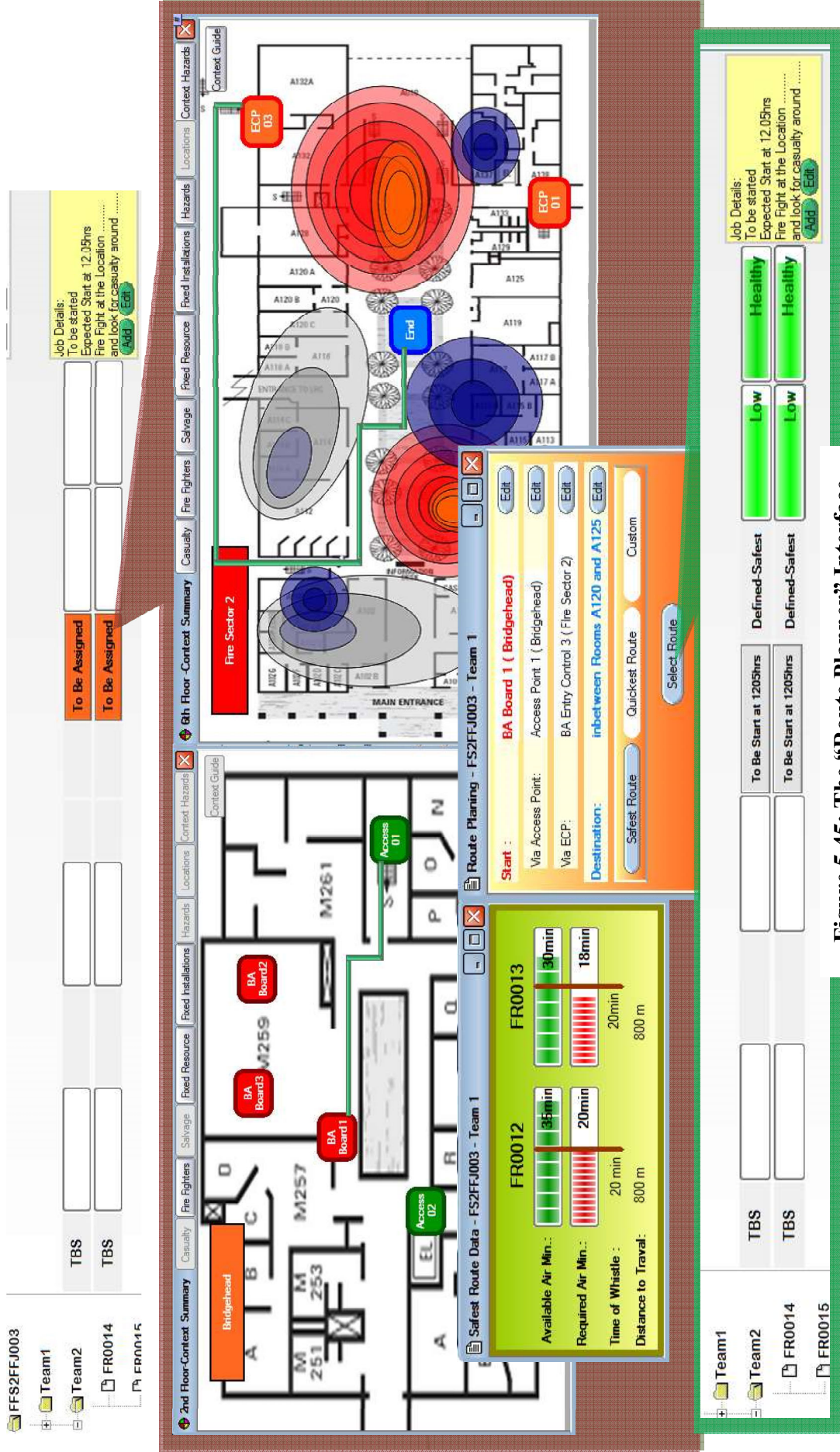


Figure 5.45: The “Route Planner” Interface

5.5 Summary

This chapter has discussed the design of human computer interface mock-ups for enhancing the SA of firefighters. The chapter has explained the considerations made in relation to the selection of interface design principles and guidelines useful for the design of the interfaces supporting firefighters during fire ER. Furthermore, this chapter has also identified important contextual factors unique to fire ER. Having considered the specific firefighter information requirements identified in Chapter 4 and contextual factors and design principles, this chapter then explained the specific design decisions adopted for the mock-up development process with the use of appropriate examples. Finally, it has explained the useful features and in-depth functionality of some of the human computer interfaces proposed. At present, there is very little literature published related to the human computer interfaces capable of delivering SA needs of key firefighter job roles during a large-scale fire. The only available literature is similar to the commercially available software such as Vector Command (Prendergast, 2007b), which primarily supports the command support teams. Restricted to a few selected proven technologies these products only look after limited requirements belonging to a particular job. Available products do not describe how to deliver the full range of requirements related to key firefighter jobs. Therefore, the software mock-ups consisting of human computer interface proposed in this chapter and the specific interface design decisions adopted in the process of interface design provide much needed design input for the IS designers and developers to maintain a healthy rapport with the client and the actual end-users of an IS that supports fire ER operations.

Chapter 6 : Evaluation of the Human Computer Interface Mock-ups

6.1 Introduction

The aim of this chapter is to explore the appropriateness and usefulness of the human computer interface mock-ups developed in Chapter 5. In so doing, it also seeks to suggest further improvements both to the design of the interfaces and to the specification of the information requirements elicited in Chapter 4, since at this stage both interface appearance and content are commented on together by the end-users concerned. This chapter analyses the outcomes of the evaluation study of these mock-up interfaces. Since this was achieved through a series of demonstration sessions, the chapter first explains the organization of these sessions. Then the chapter explains the process of eliciting relevant and useful participant's feedback. This feedback is analyzed into various themes for evaluating or improving the performance of the proposed system. These themes are considered under several headings. At first, to explore their significance, the relevance of the factors that may cause Situation Awareness (SA) failures and their general impact are explored. Then the overall appropriateness and usefulness of the interfaces in presenting information are discussed. This is followed by comments on particular strengths of specific interfaces before various limitations are explored, and some suggestions to overcome these limitations are proposed. Finally, general points about the development process of a fire Emergency Response (ER) system, the information requirements and content of the interfaces are discussed.

The detailed findings related to each theme presented in this chapter add to the knowledge of previous studies on the Human Computer Interaction (HCI) of firefighters such as Large Displays for Incident Command (Jiang et al., 2004b), Siren (Jiang et al., 2004a), Fire (Wilson et al., 2005) and Bretschneider et al. (2006), which investigated some specific HCI needs of firefighters. However, unlike in the previous studies, the findings presented in this chapter do not focus on one specific technology or a few specific needs, but cover a much wider scope of issues related to presenting information to firefighters. Moreover, the findings presented in this chapter compliment the previous work related to the design of systems to enhance SA in complex domains. There have been a few previous studies related to the jobs such as Air Traffic Controllers (Endsley et al., 2003b) and Army Officers (Endsley et al., 2003a; Jones et al., 2003), which discuss the applicability of SA oriented

design and effects of SA related failures in systems design, but there is currently no evidence of published work in the domain of fire ER. Thus, the work presented in this chapter is among the first to investigate end-user feedback related to the above concepts.

6.2 Demonstration of Mock-ups

Demonstrations of the mock-ups developed in Chapter 5 were carried out to obtain feedback and comments in relation to the presentation of information. These demonstration sessions were focused on assessing the capability of the proposed human computer interfaces in displaying or delivering information to enhance SA. The outcome of these sessions was used to re-validate and improve the specification of the previously elicited information requirements. The demonstration sessions also provided the opportunity for identifying user preferences and perceptions related to the interface design considerations made earlier in the mock-up development phase of the study, including considerations related to the devices feasible for deploying the interfaces proposed.

6.2.1 Selection of Participants

Participants for the demonstration sessions were selected to cover the target population of the end-users. To improve the richness of the feedback, participation of third party experts representing the Fire and Rescue Service (FRS) and other fire related organizations were also included. As described in Chapter 3.8.4., a mix of “Homogeneous Sampling” (Patton, 2002), “Snowball Sampling” (Patton, 2002) and “Theoretical Sampling” (Strauss and Corbin, 2008), strategies used for the previous validation sessions were adopted for the selection of participants. In the process of selecting the participants, the potential end-users of the actual Information System (IS): 1) who had some previous experience of this particular study and 2) who did not participate in the previous steps of this study were selected. The decision to select participants without any previous experience of this study was taken to nullify any unwanted favourable or unfavourable bias due to their previous interaction with the study. Furthermore, an effort was made to select participants from FRS brigades of different counties. It was a challenge to form groups due to their conflicting job schedules, particularly when they represent brigades of different counties. This difficulty could have led to a higher number of demonstration sessions being required causing inevitable time management difficulties. To minimize this difficulty, it was decided to select Subject-matter Experts (SMEs) who are capable of providing feedback for multiple

job roles, so reducing the number of sessions needed to cover all the job roles. Therefore, SMEs who are capable of providing feedback for both IC and SC job roles were selected. Similarly, a separate set of SMEs capable of providing feedback for the job roles of BAECO and BA Wearer were also identified. As shown in Appendix 6.1, the participants selected for the evaluations were as follows:

- Four SMEs already familiar with the study and capable in both IC and SC job roles (Four Sessions).
- Four SMEs already familiar with the study and capable in both BAECO and BA Wearer job roles (Four Sessions).
- Three Groups consisting of senior managers capable of providing the feedback for the job roles of both IC and SC (Three Sessions).
- Three Groups consisting of BA Training Staff capable of providing the feedback for the job roles of both BAECO and BA Wearer (Three Sessions).

These participants were drawn from the FRS brigades of Derbyshire, Leicestershire, and Nottinghamshire. In addition, the Command Support (CS) teams of the two counties Leicestershire and Derbyshire were also selected as the participants for the evaluations of IC and SC mock-ups. This selection was made due to their active participation in the process of information management in relation to the IC team. Halfway through the demonstration sessions it was decided to seek the participation of staff members who are responsible for preparing operational procedure documentation and the risk assessment documentation of high-risk buildings belonging to Leicestershire and Derbyshire. These participants were added because it had become apparent that these officers are capable of providing useful feedback specifically related to the data entry interfaces. Finally, a team of three fire prevention experts representing the Fire Protection Association of the UK were also selected as the participants. This team was expected to provide some useful independent third party feedback for the interface mock-ups developed for all four fire fighter job roles.

6.2.2 Walkthrough and Workshop Sessions

As described in Section 3.8.4, the demonstration of each mock-up consisted of two phases: Mock-up Walkthrough Session followed by a Workshop Session. A guideline consisting of several hypothetical scenarios was used to maintain the consistency of conducting the Walkthrough sessions. As an example, Appendix 6.2 shows the Walkthrough guideline

used for the combined demonstration sessions for the job roles of IC and SC. During the Workshop sessions, participants were requested to use the mock-up interfaces on their own to carry out the hypothetical tasks described. During these sessions, participants were encouraged to ask questions and comment on any of the interfaces proposed. After the two phases of each demonstration, there was a discussion session to obtain some in-depth feedback in relation to the performance of the human computer interfaces. This was supported by a simple discussion guideline (Appendix 6.3) consisting of three main discussion topics:

- Topic 1 – Performance of the interfaces proposed:
 - Related to the capability of supporting the decision-making of firefighters and thereby improving the effectiveness of the performance of their response operations.
 - Related to the performance drawbacks and means of overcoming them.
- Topic 2 – Possible design failures due to SA Demons and how to avoid them.
- Topic 3 – Feedback on the Controllability and Deployment of the interfaces.

For each topic, several open-ended questions were used to obtain the participant feedback and a digital voice recorder was used to capture the discussions. A single member of each team of participants was encouraged to represent all the other members. This request was made with the aim of reducing the complexity of transcribing the discussions. Later, these voice files were repeatedly played back to identify any valuable comments. Thereafter, the captured pieces of information relevant to each demonstration session were transcribed.

More often, the feedback sessions were in the form of an informal discussion addressing various issues related to the interfaces. This allowed participants more freedom to express their opinions. This informal nature of the discussion meant some participants deviated onto unrelated comments. In addition, there were pre-discussions before a participant reached a conclusive remark on a particular discussion topic. It was decided only to capture useful discussion points into the transcription rather than transcribing an entire session. Furthermore, it was decided to categorize the received feedback into meaningful categories (Dey, 1993). This was expected to reduce the level of abstraction to a manageable level during the analysis of the feedback (Dey, 1993). A template consisting of the following categories was used for each of the transcripts.

- a) Two discussion prompts used for the topic of *Performance of the mock-ups* (Appendix 6.3). These were tabulated against the selected main categories of the human computer interfaces proposed.
- b) Eight discussion prompts used for the topic of *Possible Design Failures due to SA Demons and How to avoid them* (Appendix 6.3).
- c) Two discussion prompts used for the topic of *Perceptions on Technology in relation to the Controllability and Deployment of the Interfaces Proposed*
- d) *Any other useful General Feedback.*

| (a) Feedback on Performance of the Mock-up | | | | |
|-------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------|------------------------------|---------------------------------------------|----------------------------------------------------|
| | Interfaces Outputting Various Incident Related Information | Interfaces for useful Alarms | Interfaces capable of supporting Data Input | Interfaces for recalling the past data (Black Box) |
| Support for decision-making and increase performance effectiveness during operations | | | | |
| Performance drawbacks and means of overcoming them | | | | |
| (b) Possible Design Failures Due to SA Demons and How to avoid them | | | | |
| Information Overload | | | | |
| Attention tunnelling | | | | |
| Workload, anxiety, fatigue, and other stressors | | | | |
| Misplaced Saliency | | | | |
| Complexity Creep | | | | |
| Out of the loop syndrome | | | | |
| Requisite memory trap | | | | |
| Errant Mental Models | | | | |
| (c) Perceptions on Technology in relation to the Controllability and Deployment of the Interfaces Proposed | | | | |
| Controllability | | | | |
| Deployment | | | | |
| (d) Useful General Remarks and Comments | | | | |
| | | | | |

Figure 6.1: The Template used to Capture Discussion Fragments Related to the IC and SC Mock-up Demonstration and Evaluation

As an example, the template used to capture IC feedback is shown in Figure 6.1. Since, on several occasions feedback for the mock-ups related to both ICs and SCs were obtained in the same demonstration session and similar happened for the demonstration of BAECO and BA mock-ups, it was decided to have just two transcript templates rather than having four separate templates. While the template shown in Figure 6.1 was used to capture the feedback of the common demonstration sessions of IC and SC mock-ups, an almost similar template was used to capture the feedback of the common demonstrations sessions of BAECO and BA Wearer mock-ups. In addition, there were few sessions in which all four types of mock-ups were demonstrated together in a single session. In these cases, two templates were appropriately adjusted to capture the relevant feedback in preparing the transcripts of this third type of sessions.

With the use of relevant template and by listening to the recorded voice files repeatedly, each evaluation session was captured as a selective transcript, which only consists of the most relevant feedback. The constant comparison technique (Boeije, 2002) was used to identify the fragments of the transcripts, which addressed some meaningful remarks or comments related to a common theme, discussing an issue or subject suitable of evaluating or improving the performance of the mock-up human computer interfaces proposed for each job role or the overall design and development of an IS for fire ER in general. These fragments were captured from the descriptions of different participants of a single evaluation session and from the participants of several different evaluation sessions. These fragments take the form of a word, a set of words, a complete statement or a set of statements.

Later, the feedback captured in the form of transcript fragments under various themes was used to extract important findings in relation to the efforts of presenting information to the firefighters. As an example, transcript fragments used to extract important findings associated with the themes related to *Relevance and impact of the SA Demons related to the design of the system* are attached in Appendix 6.4. These findings form the basis on possible suggested changes and modifications to the mock-up human computer interfaces proposed for each job role. Such improvements are crucial for the development of usable human computer interfaces of the actual IS.

6.3 Findings from the Demonstration of Human Computer Interface

Mock-ups

Careful investigation of emerging themes generated by the evaluation feedback led to grouping them into several headings as follows.

- Relevance and impact of the SA Demons related to the design of the system
- Overall appropriateness and usefulness of the interfaces to presentation of information.
- Specific design strengths of the interfaces proposed and suggestions for further improvement.
- Specific design limitations and failures of the interfaces proposed and recommendations to overcome them.
- Other important findings useful for the development of fire ER IS

The following sections explain the detail findings related to the each theme, grouped under the each heading described above.

6.3.1 Relevance and the Impact of the SA Demons Related to the Design of the System

As described in Chapter 2, Endsley et al. (2003b) identified eight possible factors that lead to SA failures and named them as SA Demons. Understanding the impact of these SA Demons and efforts of minimizing such impacts in the process of design and development of a system is important (Endsley et al, 2003b). Although such effort may not guarantee a perfect IS capable of enhancing SA, efforts to minimize such SA Demons may bring the system design in the right direction (Bolstad et al., 2006). Since this study is primarily aimed to enhance the SA of various firefighter job roles, it was decided to investigate possible SA failures specifically in relation to the design of an IS for fire ER. As explained in Section 3.8.5, this investigation was primarily focussed on the relevance of the SA Demons, their level of impact related to the design of the system and how to minimize such impact and specific SA failures in the proposed interfaces.

Finding 1: SA Failures due to Information Overload

The feedback of six out of eight individual participants and seven out of nine group evaluation sessions (Appendix 6.4) confirmed that information overload is one of the key elements that should be minimized during the design of the IS. However, feedback also

suggests that too much control over the delivery of information may easily lead to a vacuum of information, so there should be a balance of the amount of information to be delivered.

The feedback supported the usefulness of embedding the information into many information layers and arranging them in a manner that they can be quickly called up on a display via a user friendly menu system. Participants appreciated this design approach as a suitable means of minimizing the information overload.

Participants also recognized the importance of an automated delivery of information via appropriate alarms. Thus, a system designer should recognize the importance of maintaining a balance of both push and pull type of information delivery to maintain the required level of information loading onto the interfaces.

According to the participants, there is always a tendency towards information overloading with the introduction of a new system, but if designed appropriately this new system can become an opportunity of acquiring more reliable information than before. At the moment, firefighters, especially those who are responsible for the job roles of IC and SC cannot avoid the receipt of duplicate information from multiple sources. Consequently, whether they like it or not, firefighters have to process too much information at once. This is often beyond their cognitive processing ability, but the need for having multiple unreliable sources can be reduced to a minimum if it is possible to introduce some reliable information sources as proposed in the mock-ups. For example, rather than having several non-integrated pictures of a situation, one graphical picture, as in the mock-ups proposed, may be adequate to make a better decision. Therefore, if designed properly, a new system may reduce the information overloading conditions common at present.

Finding 2: SA Failures due to Attention Tunnelling

In nearly 90% of the individual and in all the group evaluation sessions attention tunnelling is identified as one of the major causes for decision-making failures among all the members of the firefighter hierarchy (Appendix 6.4). Indirectly, it can affect the safety of any person on the incident ground. To avoid attention tunnelling, participants identified the importance of understanding what is happening across the whole of the incident ground. For the higher-level command job roles, participants supported the concept of “Dash Board” as the ideal

solution capable of providing a comprehensive view covering the whole incident. Furthermore, because of the high amount of information that needs to be considered all the time and the high frequency of rapid or sudden hazardous conditions, participants indicated the need for appropriate use of alarms. Simultaneously, they described the improvements that could be achieved by maintaining a record or a list of alarms already occurred and its current status. According to the participants, these multiple methods together can reduce the attention tunnelling of higher-level commanders to a minimum. In relation to the frontline firefighters, participants recognized the possible increase in attention tunnelling due to inappropriately designed visual displays. Participants were in agreement that the possibility of attention distraction due to the use of a visual display could be reduced by combining it with audio messages, since firefighters are already trained to work with the voice commands. However, as indicated by the feedback, even such combined solutions could cause disasters since the delivery of an alarm can force the end-users to switch their attention. This rapid change of attention at the point of an alarm can bring more harm than safety as firefighter can be forced to ignore his/her current focus completely, which can be much important than the situation delivered via the alarm. For example, a sudden shift in attention of a firefighter due to an alarm, who is walking on a deteriorated floor, could lead them to fall through.

Finding 3: SA Failures due to Work related Stressors

The feedback received from more than 60% of individual and 80% of group evaluations (Appendix 6.4) confirmed that work related stressors are possible causes of decision-making errors or failures. The impact of this particular failure point can be three fold: 1) various existing stressors may lead firefighters to inappropriate use of the system, 2) better system support could lead to reduce the work related stressors and 3) there is a possibility that an interface of a system could generate additional stressors due to its improper design features. Participants explained how easily a new system can add stress to the minds of firefighters. For example, most participants mentioned the display of health indicators such as heart rate to a firefighter who is already stressed as a means of further stress. Therefore, any new system should not only seek to reduce possible work related stressors, but also be careful not to introduce new stressors. The participants felt that the proposed design features such as “Black Box,” “Dash Board,” “BA Board” and use of alarms could be useful concepts for reducing the workload and time pressure of various fire and rescue job roles. Furthermore, they emphasized the importance of introducing design features such as

relief management as it can have a direct impact on reducing welfare related stressors. Participants also described the difficulty of controlling the stressors due to physical conditions. However, they pointed out that by embedding some useful intelligent features such as firefighter navigation, a system may be able to provide the option of avoiding such physical stressors rather than trying to control them.

In general, it is evident that the proposed type of system could minimize the workload, time pressure and welfare related stressors as well as help to avoid the physical stressors common in the incident grounds. However, participants indicated that there are many other work related stressors of firefighters, which are difficult to minimize with the support of the proposed type of system. Participant also indicated that there is a greater possibility that this type of stressors can lead a person to misread an interface, carrying useful information that needs his/her immediate attention. According to the participants, in such a situation even the most useable interface proposed could fail to support the end-users. A senior officer, who is expecting a promotion, was indicated as an example of a person who is having some form of a stress, which is directly not related to the actual incident, but may affect the performance of the officer.

Finding 4: SA Failures due to “Misplaced Salience”

The feedback received from more than 50% of both individual and group evaluation (Appendix 6.4) supported the concerns about the impact of *misplaced salience* related to the design of the IS. The feedback indicated that it is important to identify the priority of information. According to the participant’s feedback, failing to do so may lead to a situation where the IS will present all the information at once. Failing to identify the salience of the information may also lead to giving much higher prominence to information that is not actually important for a particular situation and not giving sufficient level of prominence to the most wanted information.

According to the participants, *misplaced salience* can easily overload the end-users and make them work hard to identify the information that needs the highest attention at that particular point of time. In addition, it may lead to incorrect interpretation of the situation in the minds of the firefighters causing them to make decision errors.

Furthermore, it was suggested that various colour, text and abbreviation schemes used to improve salience of information may create more chaos unless they are interpreted correctly by the end-users. Participants pointed out that using only the colours to impart the prominence of information may fail to provide the necessary salience expected. Although it is not common in the FRS, colour blindness of the officers can cause such failures. Interpretation mismatch of text and abbreviations were also identified as a reason for them to fail as a means of salience. If end-users fail to interpret such text and abbreviation schemes as expected, there is a danger of misinterpretation. Therefore, it will be important to discuss in detail with the end-users the selection of colour schemes, text and abbreviations that use to indicate the prominence of information.

Furthermore, participants emphasized the danger of having too many or inappropriate alarms or alerts. In the mock-ups developed, alarms are used to grab the attention of the end-users. As emphasized by the participants, too many alarms may negate the whole purpose of their use since end-users may not respond them and just ignore them. Therefore, if alarms are to be used to highlight the salience of a situation they must be only use sparingly and must be delivered to the correct person. Another danger is that inappropriate alarms may reduce the salience of the most important information by shifting the attention of the end-user to some other insignificant information, and so leads to decision-making errors. Therefore, the use of methods or techniques that generate salience of information must be carefully selected, and there must be control in using them. Thus, it is important to understand the differences of salience required of the identified information needs. ISs failed to recognize such differences in salience when presenting the information may hinder the end-users SA rather than promoting it.

Finding 5: SA Failures due to System Complexities

The feedback of seven individual participants and seven participant groups (Appendix 6.4) suggested that too many layers of information or menus may lead to complexities in accessing the system interfaces. The participants indicated that such complexities may slow down their decision-making process, and suggested transferring some information in the lower layers to the top most layers to reduce these complexities. However, the importance of avoiding too much information transfer to the top layer was also highlighted. Thus, maintaining an appropriate balance is essential. Simultaneously, it was learnt that

inconsistent use of colours, symbols and notations may bring unwanted complexity to the interfaces.

It was further revealed that the amount of training required is closely related to the system complexity. Less complex systems reduce the need of extended training, especially in a situation when single end-user is to use multiple modules of a system (Example: Senior firefighter takes the job of a BAECO during an incident or when officers change the job responsibility from firefighter to BAECO due to a promotion). End-users require training on several modules rather than on a system module use for a single job role. However, maintaining consistency and standardization of the functionality and appearance across system modules will mean that officers need less time to be familiarized with a system module belonging to their new job role. Therefore, reducing system complexity can lead to a reduction in the cost and the time of organizing systems training sessions significantly.

Furthermore, the feedback indicated that providing an option of higher-level end-user customization to organise information around the goals may also reduce the complexity of the proposed system. Such an option may lead to quick decision-making and avoid partial SA caused by the unwanted system complexities.

Finding 6: SA Failures due to Out of the Loop Syndrome

It is evident that too much automation can take the end-users out of the loop of SA and the decision-making cycle (Appendix 6.4). In fifteen out of nineteen evaluation sessions firefighters strongly reject the necessity of too much automation. The fear of automation is one of the reasons firefighters seek to keep their decision-making away from the use of the technology. Firefighters recognized the importance of keeping in touch with the environment and operations. Thus, any system that supports firefighters should only seek to enhance their SA rather than automatically make the final decision and should allow active participation during the decision-making. The participants feared that too much automation may turn firefighters into passive operators, and in the long run they become too reliant on the system, which may lead to decision-making failures. However, one of the positive requests was to automate routine jobs, which may consume time. Jobs such as calculating “Time of Whistle,” “Turnaround Time” and identifying firefighters who need *relief* were identified as examples. In summary, a system should be designed so that it supports the decision-making by providing Level 1, Level 2 and Level 3 information to enhance the SA,

but it should not make the final decision. The system should always provide enough room and control for its operator to make the final decision.

Finding 7: SA Failures due to Limited Working Memory

It is evident that firefighters have to remember many things in their working memory and have to process them rapidly to make decisions (Appendix 6.4). New Information is generated rapidly during a fire response operation. However, human decision-making takes place at a comparatively lesser speed. Comments of five individual participants and six group evaluations emphasized that they often had too much to remember, which inevitably lead to a working memory bottleneck and to lose or forget some of the vital information. It was emphasized that it is very important to recognize the limited memory capacity of the firefighters and try to reduce the burden for it. According to the feedback, one way of achieving this is to use graphics to a greater extend. This may create a mental picture as early as possible in the minds of the end-users rather than expecting them to use the system information to make their own mental picture from the scratch. This allows end-users to maintain free space in the working memory, for them to use it for processing other important decisions. Moreover, this free space can be used to collect additional information from other third party sources that could not be captured by the system to improve the initial mental picture generated by the system. According to the received feedback, another way of reducing the burden on the end-user's memory is the use of appropriate alarms.

It was also suggested that balancing voice related and visual related technologies may help avoid working memory bottlenecks. The participants pointed out that voice commands from a system mean the end-users have to remember a lot of things mentally. Although they agreed that visual displays avoid such short comings, participants showed their understanding on the negatives that could be created due to too much visual imagery. Consequently, participants strongly recommended having a balance of both voice and visual technologies to deliver information.

It was identified that the concept of "Black Box" interface can be used to minimize the mental stresses of most of the firefighting job roles. With the support of the "Black Box" frontline firefighters may not have to devote their working memory to make mental maps when they carry out operations. Therefore, it can free-up the working memory of the firefighters so they can use it for other important activities. Similarly, with the support of

the “Black Box” ICs can have assurance that all useful information for the post incident consideration as well as for on-site briefing is collected.

Finding 8: SA Failures due to Inappropriate Mental Models

It was evident from the feedback of three individual and five group evaluation sessions that with the use of non-standardized measuring units and scales, there is a possibility of an erroneous model in the mind of a firefighter (Appendix 6.4). Use of non-standardized measuring units that differ from FRSs standards may subconsciously lead an end-user to an incorrect mental model. The risk of a firefighter creating an erroneous model mentally is exacerbated by the difficult operating environments and limited time for decision-making. This can become severe if the ISs design ignores the standards used by the FRS in relation to various symbols, abbreviations, measuring units and other exclusive terms. Hence, it is important to use familiar measuring units, notations and abbreviations. In addition, it was indicated how use of colours could lead to erroneous mental models, especially in relation to the colour blind officers.

Although the SA Demons identified by the Endsley et al. (2003b) are based on the findings of many of the previous SA related research, which are useful to understand the SA failures (Bolstad et al., 2006), there is not enough evidence to verify their significance and impact in the process of ISs design. In that context, these eight findings are important as they are based on end-user feedback, and so justify the significance of considering SA Demons in the design of SA oriented ISs.

6.3.2 Overall Appropriateness and Usefulness of the Interfaces Proposed

This section explains the detail findings related to the themes describing the success of the mock-up interfaces proposed in terms of the overall appropriateness and usefulness in supporting decision-making during fire ER operations.

Overall Strength 1: Success in the Presentation of Information

At least in one instance, end-user feedback received in seventeen out of nineteen evaluation sessions confirmed the overall success of the mock-ups proposed considering them as a representation of an IS. For all the job roles, participants showed their approval in accepting the mock-ups as an IS consisting of human computer interfaces capable of supporting their ER operations. More than 80% of them mentioned that interfaces proposed matched with

their expectations of an ideal system and considered the interfaces proposed has managed to present their information needs in a manner capable of supporting their decision-making. However, more than two thirds of the participants mentioned the importance of carrying out some modifications before these mock-ups become appropriate. The details of these modifications are discussed later.

This can be taken as an indication of a high-level of success of the mock-ups in converting information needs into its deliverable or presentation mode. Importantly, most of the feedback extracts used in reaching this particular learning point were from the participants who had some previous experience of this study; particularly during the validation phase of the GDI diagrams. Hence, appropriateness of taking these comments as an indicator of success is justified.

Overall Strength 2: Usefulness of Information Output Interfaces

Comments received nearly 90% of the evaluation feedback in relation to both IC and SC mock-ups clearly suggest that despite some specific modifications on certain interfaces, the information output screens proposed are capable of improving the decision-making capacity and operational effectiveness of both ICs and SCs. The feedback showed that the ICs prefer to use the summarised information screens more frequently than the SCs. On the other hand, the graphical screens showing in-depth details of internal and external context are more useful for various functional and operational SCs. The simple and quick combination of graphical information layers to deliver comprehensive decision-making support was appreciated by most of the participants. Participants also highlighted the usefulness of these graphical interfaces to increase their forecasting capability. Thus, participant feedback justify that it is important to provide the correct mix of summarised information, more comprehensive and focused information with projection or forecasting capability.

The feedback also described the importance of providing the flexibility for the end-users so that they can select their own combination of information rather than restrict them only to the system generated information. It was also commented that the proposed interfaces provide quick access to summarised information and more comprehensive graphical interfaces in such a way that it helps end-users to minimize decision-making time.

The feedback suggests that ICs and the SCs will be enabled to make the most appropriate decisions rather than making the safest decision if the information is accurate and timely as in the interfaces proposed. According to the 80% participants representing IC and SC jobs, ICs and SCs currently have the tendency to make the safest decisions as they do not get enough accurate and timely information to make the most appropriate decision. This shows that these interfaces can create an impact on the decision-making attitude of the end-user. The feedback also revealed that the type of interfaces proposed not only lead to better decision-making, but create extra time for the decision-making cycle of the ICs and SCs. Thus, these interfaces can provide extra flexibility for the IC team to carry out their operational activities.

The specific feedback from CS teams from both Derbyshire and Leicestershire confirmed the interfaces can primarily support the IC and the Incident Command team in general. The CS teams also believe that they could use these interfaces to improve the effectiveness and efficiency of the IC team including their own performance.

More than 75% participants in the BAECO and BA Wearer mock-up demonstrations sessions also indicated their positive response towards the mock-ups in relation to their own job roles. They described how the interfaces deployed inside the fire engines can help them to prepare physically and mentally to carry out operations as and when they arrive at the incident. This would be an important help in getting familiarized with more specific and detail information on what is happening in and around the location or the sector of an incident prior to their arrival on-site.

More than 50% of the positive feedback also suggested that the mock-up interfaces proposed for BAECO and BA Wearer might facilitate the FRS to modify or change the existing fire and rescue procedures, which are currently considered as complex or poorly performing. Participants described the possibility of extending their mental and physical flexibility due to the proposed modifications and changes to their existing work procedures and methods. For example, with the introduction of the feature: *BA Wearer Navigation*, the proposed interfaces are expected to reduce the mental and physical workload of both BAECOs and BA Wearers. Thus, effectiveness of the performance of both BAECOs and BA Wearers are expected to improve significantly.

Overall Strength 3: Usefulness of Appropriate Alarms

The feedback from all four individual participants and three groups representing BA Wearer job role and the group of fire preventive specialists revealed the usefulness of the proposed alarms for success in decision-making. It was suggested that appropriate alarms not only improve their decision-making, but also allow BA Wearers to become more flexible both mentally and physically during their operations. It minimizes the stress on the BA Wearer's basic senses like ears and eyes. Apart from providing basic alarms on the use of resources, feedback indicated the importance of providing the support of alarms for BA navigation to increase physical flexibility of the firefighters. Feedback from more than 80% of the participant representing the ICs, SCs and BAECOs also indicated the importance of appropriate alarms. It was confirmed that the appropriate use of alarms allows the ICs and SCs to maintain a better balance in their attention to the many activities and incidents happening on the incident ground. According to BAECOs feedback, alarms can reduce work pressure in situations when they have to deploy many numbers of BA Wearers from a single BS Board. The concept of repeating an alarm at predefined time intervals appears to be crucial for events, which have not already received the required level of attention of the end-users.

The appropriate use of alarms is crucial for exceptional conditions or time dependent information (Wickens and Hollands, 2000). Similar to the operators in the time-critical and complex domains such as aviation, nuclear, medical; firefighters are working with many competing goals within a very short period (Klein, 1993). This can lead to them being presented with a large amount of information at once, which is beyond their mental capacity. The participant feedback confirms the use of appropriate alarms as a means of enhancing the SA of firefighters during fire ER. Thus, it complements the previous work related to the use of alarms in time-critical difficult environments.

Overall Strength 4: Usefulness of Appropriate Data Input Interfaces

The participants of sixteen evaluation sessions including the group of third party specialists commented that appropriate data input interfaces are vital to enhance the capacity of information output interfaces. Simple and user friendly end-user data input screens play the role of a human sensory node by encouraging end-users to input their own information. According to the participants, the output screens could have been seen as being biased due to too many nonhuman sensors and insufficient human data input. This may lead

firefighters to lose the trust on the system as they are not ready to rely totally on the nonhuman sensors. Yet, according to the participants of nine sessions, the data input screens proposed are appropriate and could make the system more balanced with the information captured from both nonhuman and human sensors. Therefore, appropriate data input interfaces play a vital role in enhancing the decision-making ability and the overall operational performance of the system end-users.

According to Maris and Pavlin (2006), humans are viewed as useful and versatile sources of information during crisis management because they are good interpreters and can recognize a rich spectrum of phenomena. The participant feedback confirms this argument. Therefore, it is essential that the system proposed for firefighters captures information from various human sources of data in addition to many other sources.

Participant feedback related to the above strengths clearly indicates the need of a system to provide information to enhance the SA of the firefighters. Regardless of the job role, participants compared their current level of SA and the increase of SA that can be expected with the type of IS proposed. Klein (2000) has recognized the necessity of SA to become successful in naturalistic decision-making process such as RPD (Klein, 1993) practice by the firefighters. Participant feedback clearly justifies the need of having better SA during fire ER to carry out complex decision-making process such as RPD. Furthermore, the feedback related to the *Overall Strength 2* reinforces the importance of providing the support of information to enhance SA in the three levels: Perception, Comprehension and Projection (Endsley, 1995). Hence, the above findings of this study justify the applicability of SA Model of Endsley (1995) in the domain of fire emergency.

Although there are several previous studies in other domains such as Military (Riley et al., 2006), Medical (Gaba et al., 1995), Naval (Kaempf et al., 1996), Aviation (Endsley, 1993; Endsley and Rodgers, 1994), Control Rooms (Hogg et al., 1995) and Emergency Medical Dispatch (Blandford and Wong, 2004), which recognizes the importance of SA in the process of decision-making, so far there is no significant SA related work done in the domain of fire emergency. Thus, the above findings of this study become significant and unique.

6.3.3 Specific Strengths of the Interfaces Proposed

Apart from identifying overall appropriateness and usefulness, participant feedback has also revealed some useful themes explaining the specific strengths of some interfaces proposed and several design decisions and assumptions made during the development of the interfaces. These themes also recommended some proposals suitable for further enhancement of the identified strengths. Thus, identified strengths and extended recommendations will lead to better design and development of an IS suitable to enhance the SA of firefighters. It should be noted that themes describe a specific strength of the proposed system which supported by the feedback of more than 50% of the relevant individual evaluations and 50% of the relevant group evaluations were selected to discuss in the following sections.

Strength 1: Usefulness of the Black Box Interface

The concept of the “Black Box” to Enhance SA for better post incident considerations was considered as one of the most useful interfaces by all the participant groups and individuals involved. The feedback explained how such an interface can improve the performance of the IC team by reducing their workload. It confirmed the “Black Box” concept can help to reduce the efforts carried out to preserve the critical information, which is used in post incident activities. This concept is capable of virtually increasing the time available, especially for the IC to look after important operational activities. Apart from its use for the post incident activities, most of the participants described its additional use as a briefing and debriefing tool within the response period. Originally, the concept of the “Black Box” was designed for the use of ICs. Yet, several feedback fragments in relation to the BA Wearer and BAECO interfaces clearly indicate the importance of storing the data in such a manner that it can be recalled later to be used for on-site briefing and debriefing sessions. The interfaces supporting such on-site debriefing have to be improved so that they can display the details of completed activities of various ongoing operations. *Catalogued Field Note Ref. 4.16 made based on the observations during BA Wearer Training on 21st (Day 6) July 2007* (Appendix 6.5) clearly indicates that currently, just after every BA operation BA Wearers put a lot of effort to describe how they carried out their operations. Furthermore, most of the time, such descriptions do not match with what actually happened. Several firefighters explained how difficult it is for them to remember places and locations when they carry out operations in very harsh conditions. Similar observations were made by the ethnographic work carried out by Dyrks et al. (2008). After carrying out extensive

observations with frontline firefighters, they explain that it is important for a team of firefighters to build and maintain a cognitive map of their operations and pass that information to the next team and their commanders. They also identified the challenges faced by firefighter to build such cognitive maps due to the cognitive workload and the difficult environment. Due to these challenges, Dyrks et al. (2008) observed ambiguity and uncertainty of the cognitive maps build by the firefighters and recognized the need of system support for such situations. Thus, the “Black Box” interface could be a useful tool to debrief an operation. In the future, rather than using a white board or paper to draw maps and plans, firefighters will be able use the “Black Box” interface conveniently to explain what happened during their operations.

The “Black Box” is one of the novel and unique concepts proposed for the firefighters to enhance their SA. At present, there is no similar product or practice used by the firefighters to enhance their SA. As well as enhancing the SA of firefighters, it could be useful to overcome SA Demons such as 1) Work Related Stressors and 2) Requisite Memory Trap. This particular conceptual interface could also be recommended for other emergency related domains where end-users struggle due to preserve information that is primarily useful for their 1) post incident considerations, 2) briefing and debriefing activities.

Strength 2: Usefulness of the “Guideline” and the “Route Planner” Interfaces

The Participant feedback indicated how “Guideline” together with the “Route Planner” can enhance the SA of frontline BA Wearers by minimizing SA Demons related to work related stressors, information or data overloading and limited working memory. The participants welcomed the balance between automation and user intervention provided in these interfaces as they are given an option of selecting a route based on their own view rather than being totally dependent on a route decided by the system intelligence. Thus, this particular feature will also minimize the SA failures by keeping the end-users out of the loop of the situation due to extreme automation. These interfaces also complement the ethnographic findings of Dyrks et al. (2008) where they identified the goal of the navigation systems based on new technologies is not only to provide directions, but support the firefighters to build their own paths. The participants also thought “Guideline” and “Route Planner” would be a welcome development for the unpopular traditional practice of using physical guidelines. Most of the previous research related to fire ER such as “LifeNet” (Klann, 2008), Gambardella et al. (2008) and “CADMS” (Walder et al., 2009) has

recognized the importance of location tracking and navigation of firefighters. Complementing this research, two interfaces proposed: “Guideline” and “Route Planner” appeared to offer the possibility of an excellent solution to that problem.

Strength 3: Usefulness of the Alarm Log

The feedback confirmed the importance of having an alarm log during an incident. For the IC and SC job roles, the option of checking a log during the incident to see if any alarms had been missed was seen as useful. The feedback also mentioned the usefulness of having an alarm log during the post incident considerations. Furthermore, the comments given by the command support teams indicated its usefulness in supporting their job role and how it can improve their support to the Incident Command teams. It was also suggested that an alarm log would help during the change of command roles. Using an alarm log, officers who takeover a particular job can quickly find out what and where are the most critical activities. This will help them to focus their attention on the most wanted areas and operations and thereby balance their workload most efficiently.

Strength 4: Use of Out of Sight and Out of Path alarms

The feedback confirmed the two alarms: *Out of the Path* and *Out of the Range* proposed in Chapter 5 as crucial for both navigation and the physical freedom of movement of the BA wearers. According to the feedback, these two alarms could dramatically increase the freedom of movement of BA Wearers, but still allow maintaining equal or higher-level of safety currently maintained with the support of physical navigational guidelines and personnel guidelines. Thus, these alarms were recognized as the two most essential alarms to be embedded in the future systems supporting frontline firefighters.

Strength 5: User Friendliness of the Data Input Tools

The feedback indicated the importance of having user friendly tools for data input. It is a challenge to motivate firefighters to enter data onto a computer. Most of the participants have shown their reluctance to type in data. Participants welcome the embedding of simple automation methods during the input of data, since it can reduce the time for data inputting and may also increase the accuracy of the data. For example, the direct manipulation technique (Shneiderman et al., 2009) provided to sectorise the incident is identified as one of the popular automation among most of the participants. However, end-users always wanted a manual data input option in case they need any unconventional entry of data. For

example, the proposed manual sectorisation option that allows the end-user to type the names of the sectors manually was identified as useful when a particular type of incident has a sectorisation plan that does not match with the current policies of sectorisation. The “Route Planner” is another data input interface commended by participants mainly because its simple and flexible direct manipulation techniques (Shneiderman et al., 2009) supporting the BA navigation. Participants also appraised the manual route planning option proposed for this interface. They indicated that by providing such manual option, a system can avoid introducing too much automation. Participants stressed that it is essential to maintain such balance between automation and manual intervention as it can support end-users in having better control of the system. The “Drawing Toolbox” and “Drag & Drop” capabilities were found to be popular for data input among most of the participants. Furthermore, the concepts of “Distance Ruler and “Distance Grid” were considered useful to provide support during drawing and positioning.

The feedback justifies the use of design guidelines in relation to the interface interaction (Shneiderman et al., 2009) and the data entry (Smith and Moiser, 1986). More specifically it confirms that the end-users of the system prefer to use direct manipulation techniques (Shneiderman, 1983) rather than other traditional techniques such as form filling or command language. However, the feedback also reinforces the preference of end-users to have some degree of manual controllability to nullify any adverse effect due to extreme automation (Shneiderman et al., 2009). The human supervisory role needs to be maintained because the real world is an open system and there can be many unpredictable events that are beyond the capabilities of a system. Manual intervention in such situations is essential to maintain the usability. As explained above, the manual options allow the end-users to override some of the less capable automation as and when necessary.

Strength 6: Appropriateness of the Display Devices Proposed for IC and SC

Most of the participants were in favour of a larger display for the IC interfaces when they are at the scene. This display can be similar to that of a Liquid Crystal Display (LCD) fixed in the new CS vehicles. However, participants had conflicting views on the size of the display device in relation to the SC interfaces. Although most of the participants preferred the use of a larger display, the working environment of the SCs and their work patterns seems to prevent the use of such a larger display and suggested the use of a laptop screen. However, the display should be able to withstand the harsh environments regardless of size

of the display. Apart from the display device for the ICs and SCs who have already arrived at the incident grounds, the feedback also highlighted the importance of providing access for both ICs and SCs who are on the way to the incident. Ideally, the most suitable display device can be a laptop located in the vehicles of the officers who are on the move.

Proposed Improvement

Further research is needed to determine the best choice of displays for the SC interfaces. A final decision should only be taken after carrying out some rigorous usability testing of both laptops and large displays during live operations.

Strength 7: Appropriateness of the Display Device Proposed for BAECO

The feedback confirms the design consideration that it is important to have a bigger and unconventional type of display device for the job role of BAECO. Essentially this should match the size of the BA board currently used in the FRS. Almost all the participant rejected the idea of using a device such as a laptop for the support of BAECO job role. For the deployment of the BA Board interface proposed, it may require an electronic device, which is to be used in difficult conditions. Hence, it is important to select a device specially designed to withstand harsh environments.

Strength 8: Appropriateness of the Display Device Proposed for BA Wearer

Almost all other participants who commented on the devices proposed for the BA Wearer interfaces emphasized that the old generation of firefighters has a fear of using new technology. Therefore, the option of HMDs for the visual interfaces could become quite a challenge among the older generation of firefighters. Yet, the feedback clearly suggests that head mounted visual displays could be a feasible option for the younger generation of firefighters. Furthermore, almost all of the participants indicated the need of physical prototypes to test the suitability of a HMD. However, none of them rejected the idea of having visual information. They were only concerned about the applicability of devices, which display such visual information.

The feedback was positive about the idea of using voice combined with a visual display to present information. Most of the participants insisted that the delivery of information should start with voice rather than a visual media. It was stressed by many participants that BA Wearers are not ready to sacrifice their hands for the operation of any third party devices unless it is directly related to their operations. This was confirmed by many field

observations. The feedback also indicated that the BA Wearers are not ready to focus their vision onto a visual display or a picture continuously for a long period unless essential. Thus, voice is recommended to be used in combination with any other suitable media. In fact, BA Wearers are already familiar with the use of voice. Currently, the fire ground communication is totally based on the medium of voice, either via the use of two-way radios or face-to-face verbal communication. Therefore, firefighters comfortably accept voice as a user friendly mode of communication.

Proposed Improvement

The proposed system not only introduces new means to acquire information and carry out BA operations, but also introduces sophisticated technologies, which have never been used by the BA Wearers. So as suggested by most of the end-users, it is recommended to start the rollout of the proposed BA Wearer module with a technology already familiar to the actual end-users. According to the participants, such a rollout is considered essential for any long term success or popularity among the potential end-users. Therefore, it is recommended to begin the testing of a physical system prototype, which delivers the information only via the medium of voice. Deployment of interfaces capable of combining both visual and voice mediums in tandem on to a handheld thermal image camera type of device is recommended for the second stage of the rollout. Finally, the interfaces can be upgraded to a much higher-level technology by combining the use of voice with a HMD type of display. Such an arrangement will allow the end-users to properly digest and adjust to a totally new concept based on a totally new technology to carry out their operations.

Strength 9: Appropriateness of the Display Device Proposed for the Fire Fighters Moving in a Fire Engine

Participants expressed their strong support for displaying the interfaces on the existing mobile data terminal screens located inside the fire engines. These interfaces will be able to provide both dynamic and static information that can be useful for the firefighters who are on the way to the incident. However, it was thought as important to locate this display at a convenient position so that all the firefighters inside the fire engine can have access to the information. In that case, they expect to carry out quick brainstorming with the support of the interfaces proposed. Currently, firefighters are not concerned about the position of the mobile data terminal as it is mainly being used as a navigator. However, with the proposed dynamic information it becomes a much more useful tool on the way to the incident and therefore, needs appropriate positioning inside the fire engine.

Strength 10: Appropriateness of Voice Controlled Interfaces for a BA Wearer in Action

Strength 8 is concerned with presenting information to the BA Wearers, but there is a separate issue of how to control any displays they use. It was suggested more than 80% of BA Wearer evaluation sessions that the most feasible way forward for control of BA Wearer interfaces will be through voice recognition. Whether the information presentation will be via a voice interface or purely via a visual interface or as proposed via a mix of voice and visual interface, the control of the interface may only be feasible via voice commands. Despite supporting the idea of voice control, participants recognized the difficulty of voice recognition due the noisy conditions on the incident ground. As a solution, all of the participants accepted the use of throat operated microphones. In fact, several participants mentioned the plans of FRS to use similar technology to improve the BA Wearer communications. Also, a participant of the Session 14 mentioned their specific experience of using such devices and explained its capability of reducing incident ground noise and improving communication.

Proposed Improvement

Participants mentioned that there are many other factors to be improved before such technology could be adopted as a proven technology. In addition, participants of the Session 15 were also concerned about the capability of throat operated microphones, since the behaviour of a BA Wearer's vocal chords can vary depending on the health level and context of the operation. Although a throat operated microphone is conceptually a feasible solution to control the BA Wearer interfaces, it may need further testing and validation before being accepted. Such testing would only be possible with the use of a physical prototype operating in an actual fire context.

Previous related work such as project "Fire" (Wilson et al., 2005) and "Siren" (Jiang et al., 2004a) identified the use of visual solutions to deploy the information for frontline firefighter. In addition, Bretschneider et al. (2006) and Wilson and Wright (2007) describe the usefulness of HMD for frontline firefighters. They were concentrating on perfecting the ergonomic design and the visual aspects of the HMD, but a very little was described in relation to the controllability of the visual interfaces. In that respect, the feedback received becomes significant, as it accepts using a throat operated microphones to control the visual display devices for frontline firefighters as an important design concept. Multimodal display concepts are not new as most of the HCI and Wearable Computer related literature such as Shneiderman et al. (2009), Endsley et al. (2003b), Brewster et al. (2003) and

Dvorak (2008) describe the usefulness of multimodal displays in delivering information. In contrast, having considered the unique work environment and possible end-user challenges, this study proposes a multimodal display concept suitable for the frontline firefighters. Apart from the frontline firefighters involved in a fire emergency in a large building, this concept could be equally applicable for similar frontline ER domains such as earthquake, volcano eruptions and wild fire rescues.

Strength 11: Ability to Dynamically Capture Information from both Human and Automated Sources

Firefighters traditionally trust humans than technology (Landergrarn, 2007). However, participants believed that the ability of the system to capture and present both nonhuman and human information together as one the important features for the end-users to increase their trust to use an IS during their operations. Having used to trust humans for generations, most of ICs and SCs strongly believe that it is essential to combine the views of other people at the incident site to understand a situation better. With the proposed system, users can add their own information dynamically into the system and others working in a different context can instantaneously share that information. So a firefighter will be able to fuse the information inputted by their colleagues working in a different location with other automated sources of information to understand a particular situation. Currently, it seems to take much longer time and sometimes impossible for ICs and SCs to collect and integrate human information to understand the situation dynamically. According to them so far, they have to either create these situation pictures mentally or on a piece of paper or on a white board. Specifically, for this purpose, ICs talked to their top command team members in 20 or 30 minutes intervals. In a dynamically changing context, with their current workload, participants consider it as an impossible task for them to update these pictures continuously, either mentally or on a paper on their own. However, at present, there is no other better option available. Thus, they believed that this type of system capable of capturing information from combined sources could provide an opportunity to build a picture of a particular situation quickly and much accurately than before. Since they have access to both human and nonhuman views at once in a much more organised manner, their confidence of understanding a situation is much higher. These views of the participants complement the SA model of Endsley (1995) and indicate the essential need of receiving both human and other automated forms of information for an individual to form accurate SA.

6.3.4 Design Limitations of the Interfaces Proposed

Having considered the possible design failures due the impact of SA Demons, the following sections describe some specific limitations and shortcomings in adopting various design decisions and assumptions. In addition to the limitations directly related to specific SA failures, it also describes some generic limitations related to the delivery and presentation of information. To minimize the impact of these design limitations, modifications are proposed so that the usability of the actual system supporting fire ER will be enhanced. Similar the discussion of the strengths, themes describe a specific limitation or weakness of the proposed system which supported by the feedback of more than 50% of the relevant individual evaluations and 50% of the relevant group evaluations were selected to discuss in the following sections.

Limitation 1: Organizing the Information around the Goals of an End-user

During the development of the mock-ups, effort was made to provide the opportunity for the system end-users to organise Level 1, Level 2 and Level 3 information around a particular goal. However, participant's feedback suggests that although the system has provided flexibility to organise the information around the goals it has not met the end-users expectations. According to the feedback, the organization of information in the mock-ups developed is predominantly based on various information sources rather than the goals of the end-users.

To use the proposed system, end-users must have a good knowledge of the relationship between a goal and the information required to achieve that particular goal. For instance, at the beginning, an end-user has to identify the exact pieces of information required to respond to a particular situation. Then the end-user has to select the relevant interface/s with the use of menus based on various categories of information. Only then, the end-user can acquire the information necessary to make a decision to achieve a particular goal. This was identified as a challenge and time consuming process for the end-users. This seems to be more difficult for novices. Also, senior officers who lack recent experience or do not have adequate experience related to the incident may face similar challenges.

With the current proposal, when an interface is called it may present essential information as well as other information, which is not relevant to the current decisions. In a complex, time constrained situation, having related and unrelated information together in an interface

will put more stress on the end-users. Therefore, the system may not be user friendly enough, especially for the novice officers and the officers who lack recent experience related to the incident they face. To overcome this, organization of information should be modified and become goal driven than information driven. Ideally, interfaces should only consist of information supporting to achieve a particular goal.

Notably, despite revealing a design limitation related to the mock-up development, feedback received justifies the importance of maintaining the SA oriented design principle of organizing the information around the goals during the design of an IS.

Proposed Improvement

Although there are many SA led research studies related to Military (Riley et al., 2006), Medical (Gaba et al., 1995), Naval (Kaempf et al., 1996), Aviation (Endsley, 1993; Endsley and Rodgers, 1994) and Control Rooms (Hogg et al., 1995) and Emergency Medical Dispatch (Blandford and Wong, 2004), none of them clearly explains how to organise the human computer interfaces to support its operator SA. Even the limited previous efforts in developing information computer interfaces exclusively based on the SA oriented design principles such as interfaces for air traffic controllers (Endsley et al., 2003b) and Army Officers (Endsley et al., 2003a; Jones et al., 2003) did not clearly define how to arrange the information around the end-user goals. To overcome this limitation in the SA oriented design guidelines, the following modifications based on the feedback of firefighters are proposed.

Having considered the participant's suggestions of twelve evaluation sessions related to implementing a better solution to organise information around the goals, it is proposed to have an option where end-user can have the support of a menu consisting of items depicting the hierarchy of goals relevant to his/her job role. With this new option, end-user should be able to control the content of information displayed via the main categories of information output interfaces proposed. With the use of an example, the following discussion explains the functionality of this conceptual modification.

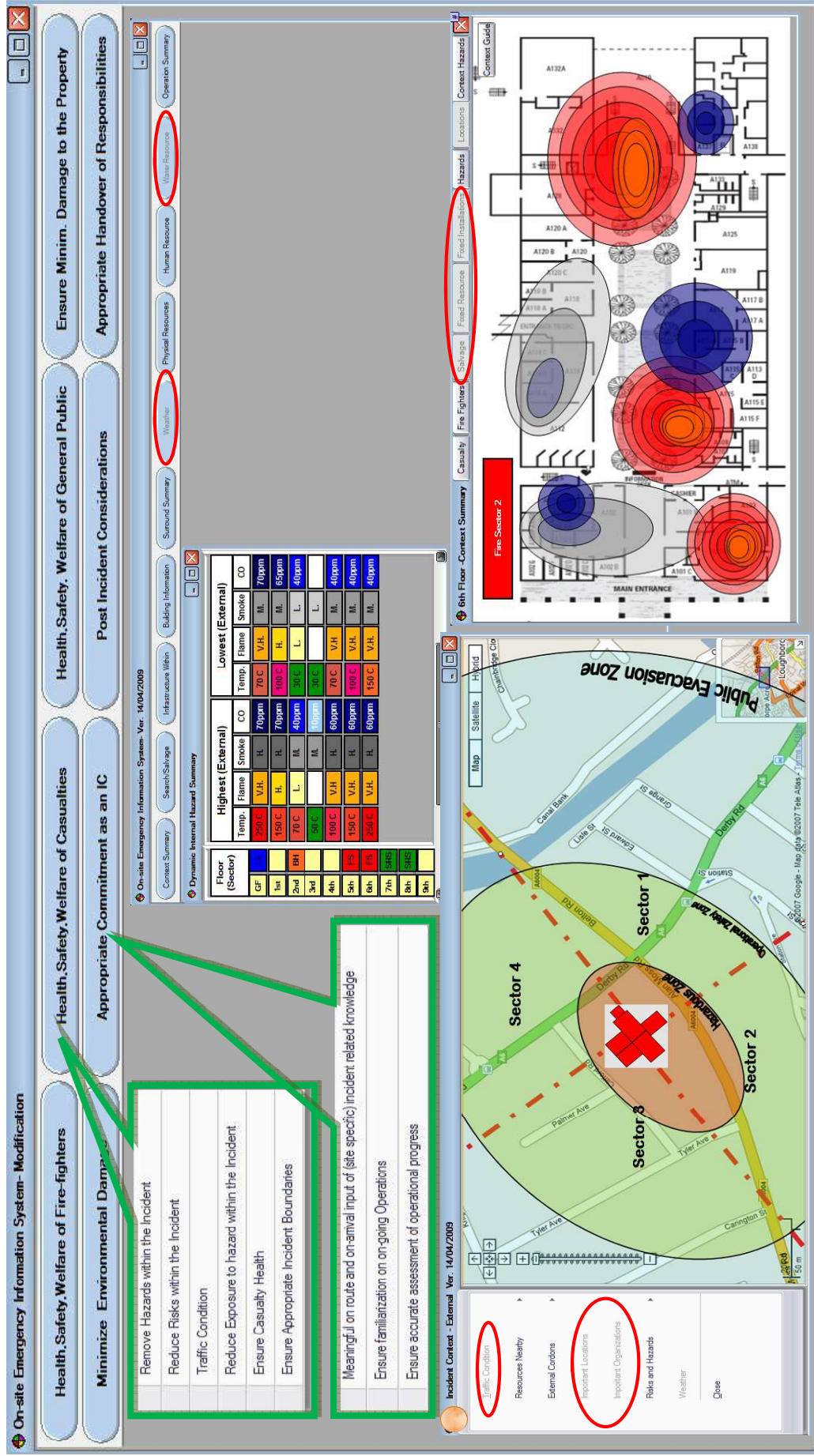


Figure 6.2: Interfaces to be Driven by Menus Consist of Goals and Sub Goals

Consider an IC working on the incident premise. As shown in Figure 6.2, the modified IC module should consist of the main menu with the top eight goals of the IC. When click each top-level goal, it should provide the end-user with a drop-down menu that contains a list of secondary level sub goals belonging to that particular goal. As an example, Figure 6.2 shows two such drop-down menus relevant for the two of the top goals: *Health, Safety and Welfare of Casualty* and *Appropriate commitment as an IC*. Different to the initially proposed mock-up for IC in Chapter 5, with the use of this new menu the end-user can now select a goal, which he/she is currently involved or wants to achieve next. By selecting a preferred goal from the proposed menu, the end-user could start the goal driven information filtering process. After selecting a particular goal, end-user will be able to call any of the previously proposed categories of interfaces onto his/her display device. As shown in the Figure, this may include the “Dashboard”; main perception type of interface capable of presenting the overview of the incident and any other categories of interfaces capable of presenting comprehension and projection level information related to both internal and external context of the incident. Importantly, after this proposed modification, regardless of the type of interface to be called onto the display device, these interfaces should now contain only the information strictly related to the goal selected by the end-user. To achieve this goal driven information filtering, it is proposed to disable all the buttons and individual menu items dynamically on all categories of interfaces, which are not relevant to the goal being selected. For example, as shown, depending on the goal being selected some of the non relevant buttons and specific menu items should be disabled.

Importantly, with this proposed goal driven feature, interfaces will support ICs to focus only on the information that needs to make decisions related to the particular goal being selected. Their level of distraction due to information overload could be minimized. Therefore, proposed modification will enable ICs to enhance SA needs exclusively related to a prioritized goal quickly. Similar changes could be made to other mock-ups representing the needs of rest of the job roles. With these modifications, end-user’s information could be successfully organised around the goals and therefore, become more capable of enhancing SA.

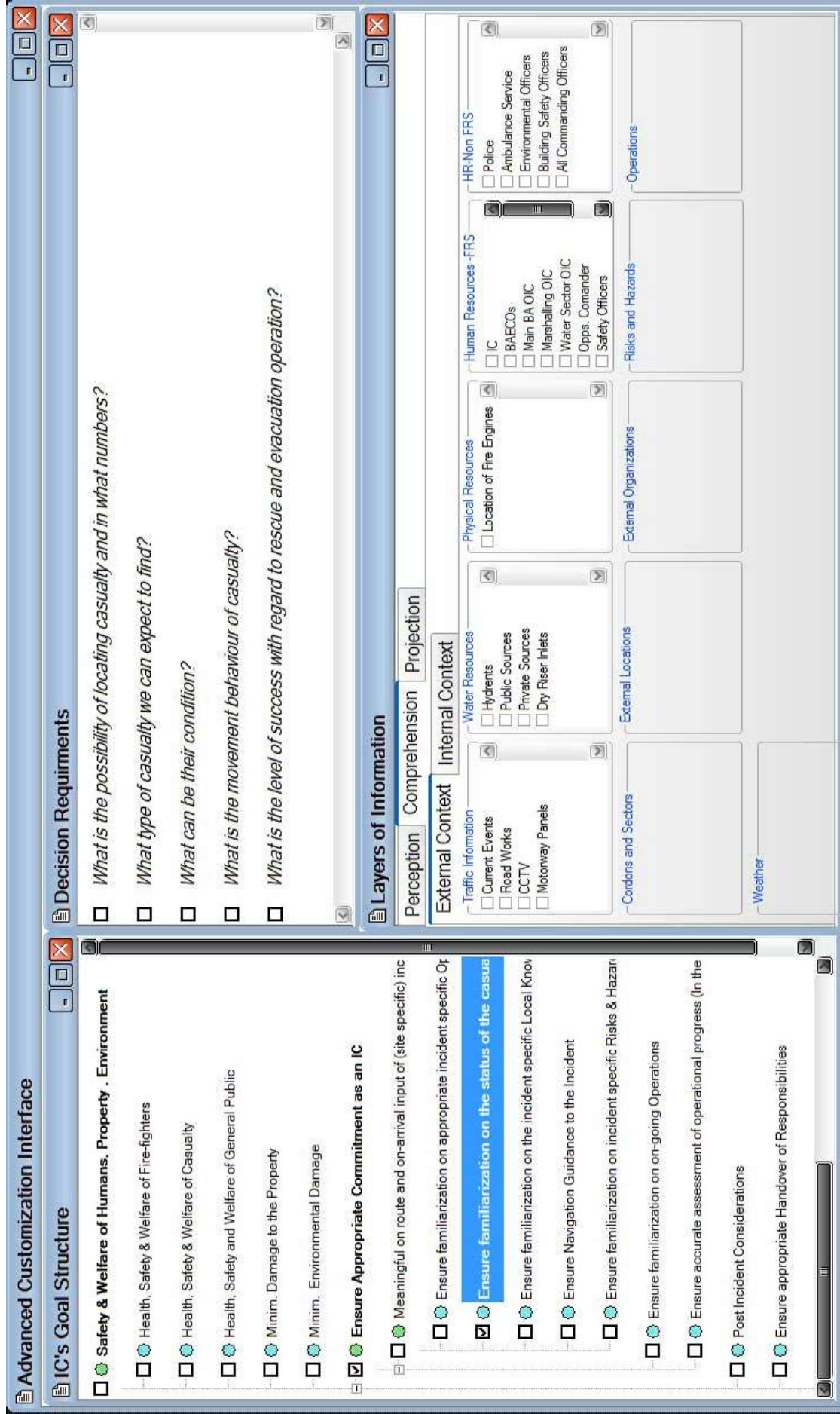


Figure 6.3: The “Advanced Customization” Interface

However, even after organizing the information around goals, due to the dynamic nature of the incident and the differences in the characteristics of individual end-user and their level of experience, the interfaces may still require further customization. This may lead to further requirements where an individual end-user may either need to add one or many information layers onto the current interface or he/she may need to remove some of the information layers. Bearing this in mind, it may not be sensible to completely replace the previous method of organizing information. Thus, interfaces should be designed in such a way that time to time, according to the end-users preference, there should be an option of enabling buttons and menu items, which are disabled. This will allow an end-user to add or delete information layers more flexibly so that they could further fine tune the system generated output. Ideally, this modification proposed should augment the functionality of the mock-ups rather than completely substitute its original design.

As a means of further extending the flexibility of organizing the information around the goals of an end-user via the above proposed interface modification, this study also proposes a new interface: “Advanced Customization.” This additional interface intends to enhance the opportunity of organizing information according to the individual needs of an end-user and supporting the successful implementation of the above proposed modification. As shown in Figure 6.3, this interface will be capable of providing the option of managing the goal and decision structures individually by the end-users themselves. This will allow end-users to add a new goal or sub goal into the existing goal structure or even to edit or delete any existing goals. Similarly, it allows add, edit or delete any of the decisions related to a particular goal/s and information layers related to any particular decision. For example, as shown in Figure 6.3, for the selected goal “*Ensure familiarization on the status of the casualty,*” which is one of the tertiary goals of the top-level IC goal “*Ensure Appropriate Takeover/Commitment as an IC,*” the end-user is given the option of either adding, editing or deleting any of the existing decision-making needs defined in the window of “Decisions.” Similar to the above example, whenever an end-user selects a goal according to his/her preference, he/she will have the capability of managing the corresponding list of decision-making needs defined inside the “Decisions” window relevant to that particular selected goal or the sub goal. Simultaneously, the “Layers of Information” window will display all the layers of information this system is capable of displaying. These information layers are categorized into three broader levels of SA: Perception, Comprehension, and Projection. In addition, there should be sub categories under each level: External Context

and Internal Context. As shown, each carry further sub-categories of various information sources related to the relevant context.

As shown in Figure 6.3, under the sub category *External Context* belonging to the SA category of *Comprehension*, there are information layers under each category of information sources such as Traffic, Water, Physical Resources and HR Resources. Therefore, depending on the end-user's preference he/she will be able to select or deselect each and every information layer. Thus, depending on the selected goal, the system will only display the layers of information according to the preference of that particular end-user. As shown in this example, the "Layers of Information" window displays a snapshot related to the selected information layers belonging to the *External* context. These layers deliver SA at the level of *Comprehension* necessary to achieve the sub goal of "*Ensure familiarization on the status of the casualty.*" Similar to the above example, the end-user should be able to select the necessary information layers related to other levels of SA. Therefore, with this higher-level customization, end-users will be able to create their own display of information depending on their needs, capabilities and the level of experience.

However, practical implementation of the above proposed higher-level customization is feasible only if a very flexible layered architecture is maintained during the design of interfaces. Therefore, system developers should make arrangements to map information onto several independent layers during the actual system development. For example, currently, the information layer *Fire Engine/Vehicle Location*, which is categorized under the *Physical Resources of an IC* is displayed via the interface showing the external context of the incident. This information layer is designed in such a way that it consists of the following pieces of information:

- Fire Engines - On-site
- Fire Engines - Deployed (Coming towards the incident)
- Other vehicles - On-site (Example: CS Vehicle)
- Other vehicles - Deployed

However, depending on the end-user, some of them do not want to see the moving vehicles. So with the customization facility, they only need to call the layers of information showing fire engines and other vehicles, which are already at the incident site. But currently, information related to both on-site as well as off-site vehicles are embedded into a single layer as shown in Figure 6.4.

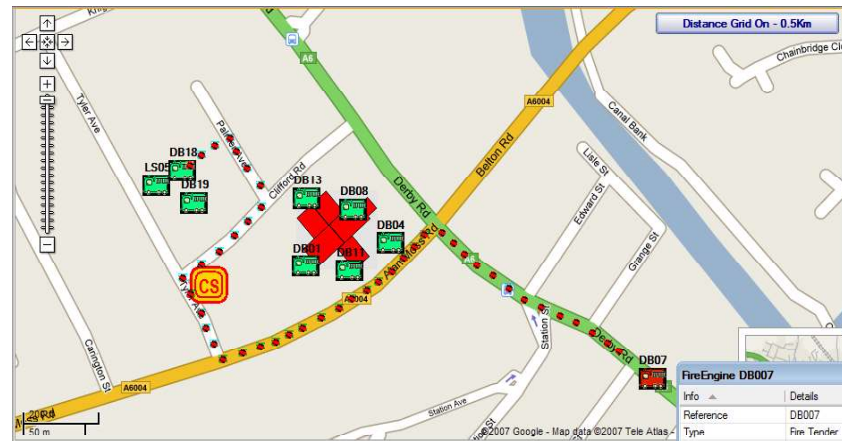


Figure 6.4: An Information Layer Displaying Dynamic Locations of Various Types of Vehicles

Therefore, to improve the customization capability of the end-user, it is proposed to split this information into two layers of information rather than one.

- New Layer 1 - all the fire engines and other vehicles on-site
- New Layer 2 - the fire engines and vehicles coming towards the incident

But for maximum customization purposes, this information could be further split into four layers where each layer carries the following information.

- Layer 1 - Fire engines on-site
- Layer 2 - Fire engines deployed (Coming towards the incident)
- Layer 3 - Other vehicles on-site (Example: CS vehicle)
- Layer 4 - Other vehicles deployed

The decision of whether to have two layers or four layers of information should be made according to the needs of the end-user. Such detail requirements should be verified before building the actual system.

These modifications proposed based on the end-user feedback further justifies the use of the design concept of layered architecture derived from the principles of “Situational Mashups” (Huang and Yang, 2009).

Limitation 2: Displaying Inappropriate and Unwanted Information for BA Wearers

It was reported that presenting their health indicators to active firefighters is not helpful. Such a practice was criticized by most of the participants. According to the feedback, it may lead to further confusion and disorientation of a firefighter who is already in an

unhealthy condition. However, it was considered important to send health information of a disoriented firefighter back to the relevant BAECO and to his colleagues who are working on the fire ground. However, all the participants recognized the value of displaying the three time scales that indicate the 1) *Turnaround time*, 2) *Time of whistle* and 3) *Time remaining till finish of breathing air*. Currently in the interface proposed (Guideline), the display of these scales can only be switched on manually by pressing a button. Nonetheless, BA Wearers tend to forget to check on this type of indicators due to the difficult work and environmental context. Therefore, it is inappropriate to provide a button to activate these indicators manually. Instead, it was suggested that these three scales, should be displayed on top of each and every screen provided for the BA Wearers continuously and prominently.

Participants also pointed out that some of the information they earlier requested to help in decision-making had now become obsolete with the new system. For example, the figures for air pressure as well as the rate of breathing were identified as important information to work out the remaining time till air pressure reaches un-breathable level. But the system proposed is capable of directly calculating the remaining air in minutes, so breathing rate has become obsolete information for decision-making. Since firefighters themselves refused to access the indicators displaying their health conditions, the need for an indicator to display breathing rate may not arise. However, the system still needs the breathing rate information to calculate the air levels in minutes; it is just not necessary to be displayed visually for any of the end-users.

Proposed Improvement

In the previous section, possible SA failures due to excessive work related stressors such as anxiety and possible misplaced salience were noted. Such failures are caused by specific design limitations in the mock-ups. Because of this, it was decided to remove the health indicators from the display for BA Wearers. However, these indicators will be continuously delivered to the colleagues of the BA Wearers and BAECOs. This will appear on the BA Board as a default indicator of *Body Health*. Furthermore, when necessary, BAECOs will have access to the individual health indicators of the BA Wearers as well. Similarly, these indicators will also be displayed whenever the SC or the IC accesses the individual health indicators of firefighters. The modified screen for the BA Wearer is shown in Figure 6.5. The indicators showing *Time of Whistle*, *Time to Turnaround* and *Air Remaining* will be continuously displayed on the left of the BA Wearer interface. Therefore, BA Wearers do

not need to call these indicators deliberately onto their screens. Furthermore, as proposed in the initial mock-up, the health monitor button, which is used to call the health indicators and the air level indicators are removed from the interface as there is no further use of such button.

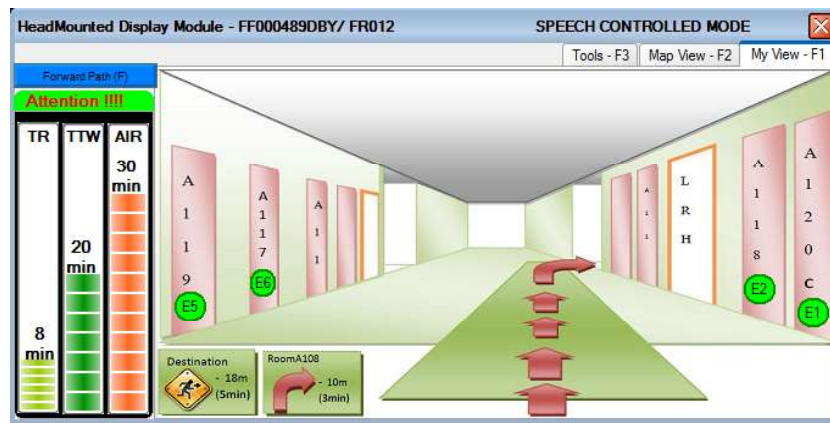


Figure 6.5: Revised Interface for Fire Fighter Navigations

In relation to the display of risks and hazards, it is proposed that the system should automatically display such information as soon as they become significant. However, each and every hazard or risk should appear on the interface only when the BA Wearer enters in to the impact area of that particular risk or hazards. Therefore, it is important to specify the timing of such display based on the type of the risk or hazards so that, displaying of hazard will become more of an automated function. This automation led to the removal of the button *Nearby Hazard*, which was originally located on the main navigation interface of BA Wearers to select manually to check the nearby risk and hazards.

According to the findings of May et al. (2007), it is not useful to send information related to health indicators to corresponding BAECO since a BAECO may not have the time or opportunity to take the responsibility of the safety of firefighters. Findings of this study indicate firefighters are totally responsible for their own safety during their operations. Therefore, May et al. (2007) suggest that it will be better if some provision is made to send health indicators to BA Wearers in operations to help them evaluate their health levels themselves. However, May et al. (2007) suggestion is contradictory to the findings of this study as participants of this study propose not to send health indicators to BA Wearers, but to send them to a relevant BAECO and to other BA Wearers working in the same BA team. According to feedback received, it is evident that the team members can make a better

judgment on the level of fitness of a firefighter. This is justified by the following comments.

Mock-up Evaluation Session 6:Also your colleagues can see how you are faring better.....actually when a BA is getting weaker and unfit best judge of assessing his conditions are his nearby colleagues..

Decision and Information Capturing Interviews (Interviewee 20 - BA Wearer):....During BA operations other members of your BA team always keep an eye on you...especially the team leaders... so each member wanted to know how others are faringare they fit to workwhat are their conditions.....as a colleague it is important to know these things..... nearby team members are the first people who can help you when you are in trouble.....

Therefore, sending health indicators to nearby colleagues is considered as paramount to enhance the safety of a BA Wearer.

It is also evident that at present BAECOs have limited ability to support the safety of BA Wearers due to the limited knowhow of the condition of the BA Wearers and their excessive workload.

Decision and Information Capturing Interviews (Interviewee 15 - BAECO Job Role): Although we want to support BA wearers desperately, it will be very difficult to look after them now ...mainly because it is very little we know about them....other thing is we have enough work like calculating time of whistle ...dynamically monitoring it for all the deployed BAs. So with all that it is impossible to take responsibility for the safety of BAs.

Goal Capturing Interviews (Interviewee 9 - BAECO Job Role):.....We want to ensure the safety of the BAs in operation but with our current work practice, it is impossible.....that is why we need better information and systems to reduce many of the time wasting aspects related to our work so as BAECOs we can provide much more strategic support in the future to carry out safe and successful BA operations...

As explained by the nearly 80 % of participants related to the BAECO and BA Wearer interfaces, currently BAECOs do not have any other option than asking BA Wearers to look after their own safety. However, this is not actually what the BAECOs want, as it is identified that one of their goals is to ensure safe navigation of firefighters. Decision-making and information requirements identified in relation to BAECO needs clearly indicate their desire to safeguard the life of BA Wearers during BA missions. These

requirements reveal that BAECO could support BA Wearers' safety better if their current workload could be reduced and if they can receive an accurate update on the BA Wearer conditions. In fact, when a BA Wearer is in a disoriented condition, BAECO is the best person to assess the conditions apart from the nearby colleagues of their BA team. The following specific comments further justified the above argument.

Mock-up Evaluation Session 7:.... after all with this type of proposed system BAECO will be in a position where they have enough time and information to assess the condition of BA wearers much better than BAs themselves.....But with our current practice don't ever expect BAECO to take such level of responsibility..... as a BAECO we have enough work now so it will be difficult to look after the actual health of BAs.....

Mock-up Evaluation Session 14:...with this sort of system, BAECO could be in a much better position to decide the fitness of BA Wearers....so they can decide when to call BA emergency...

Having considered the above, it can be argued that with the implementation of the proposed type of system, BAECOs will be able to support to enhance the safety of the BA Wearers and could provide a better judgment of fitness and health of the deployed BA Wearers.

Limitation 3: Displaying Inappropriate and Unwanted Information for BAECO

The participants indirectly mentioned that it is important to improve the clarity of the current BA Board interface further. They indicated that too much space on the BA Board is occupied by few unwanted information. Hence, it is proposed to remove the information, which does not have any value towards increasing the end-user's SA. Most of the participants indicated that the column of information that shows the *End-time* of operation on the BA Board interface, which indicates the remaining time till the BA Wearer's cylinder become empty is a piece of information that does not add any value to the BAECOs SA.

Proposed Improvement

Bearing in mind possible SA failure due to information overloading, the *End-time* column of the BA Board display will be removed, allowing more space for other important information, which may help to improve the clarity of the display.

Limitation 4: Displaying Personal Information

It was learnt that it is important to be careful when displaying personal information for ethical reasons. For example, it was explained that it may not be appropriate to display the

medical history of a firefighter publically. Such practice may lead to unwanted work related stress. Therefore, when presenting this type of information, it is vital to define an appropriate level of authority to access such information. Interestingly, a person's blood group and drug allergies are considered less controversial socially. Therefore, such information can be presented directly to any O.I.C, since sometimes it can be useful to save a life during an incident.

Limitation 5: Limited Number of Interfaces Capable of Enhancing Level3 SA

Feedback received in sixteen out of nineteen evaluation sessions revealed the importance of enhancing the decision-making support by providing Level 3 SA: Projection interfaces, which are capable of predicting situations and suggesting options or solutions for decision-making. Participants were confident that such intelligence will improve their decision-making and therefore, save valuable time. Participants also described how the reduction of decision-making time indirectly helps to improve the flexibility in carrying out the rest of the response operations. Their feedback in twelve evaluation sessions also indicated limitations in the mock-ups specifically in relation to Level 3 SA and suggested some specific interfaces that will further enhance their SA.

Proposed Improvement

The following new interfaces capable of improving Level 3 SA of the end-users are proposed:

- Prediction on outside evacuation zones.
- Prediction on structural stability or building collapses.
- Prediction on most appropriate water resources and physical resource necessary to access such water resource.
- Predictions on early incident settings such as most appropriate rendezvous, riser and water drains to be used.
- Showing best human resource options available to carry out a particular activity or task.

Limitation 6: Inappropriate Use of Colours

It was indicated that the inappropriate use of colours in some of the interfaces could cause system failures in a situation where the end-user is colour blind. However, almost all the participants accepted that the system must not gear only to support the colour blind people. The following limitations in the use of colours were mentioned by the end-users.

- a) Use of colours to deliver the meaning of contextual hazards (Context Guide).

- b) Use of colours, text and symbols to indicate the working status of equipment (Sprinklers).

According to the participants, interfaces consisting of these types of entities may lead to possible failures in decision-making when use by the colour blind officers.

Proposed Improvement

Before presenting any improvement, it was important to recall that 1) majority of the officers of the FRS are not colour blind, and the colour blind percentage is much smaller in FRSs compared to the general public, and 2) Officers of the FRS already use colours to its maximum potential in their systems. Therefore, it was decided to continue to use the colours to their full potential to convey information, indicate an action, prompt a response or distinguish a visual element. However, to keep a balance so that the system will support both the minority of colour blind and the majority of non-colour blind users, certain additional design considerations are proposed to mitigate the issues in relation to the use of colours.

- a) It is not appropriate to use the colour as the only visual means of conveying information. It is proposed to use colours combined with different lines styles and line thicknesses to demarcate different types of hazards (Figure 6.6). Furthermore, use of a key (Context Guide) and use of a single hue with intensity variations from light to dark or pale to bright to indicate the variation of various contextual parameters will improve the use of the interfaces for colour blind end-users.

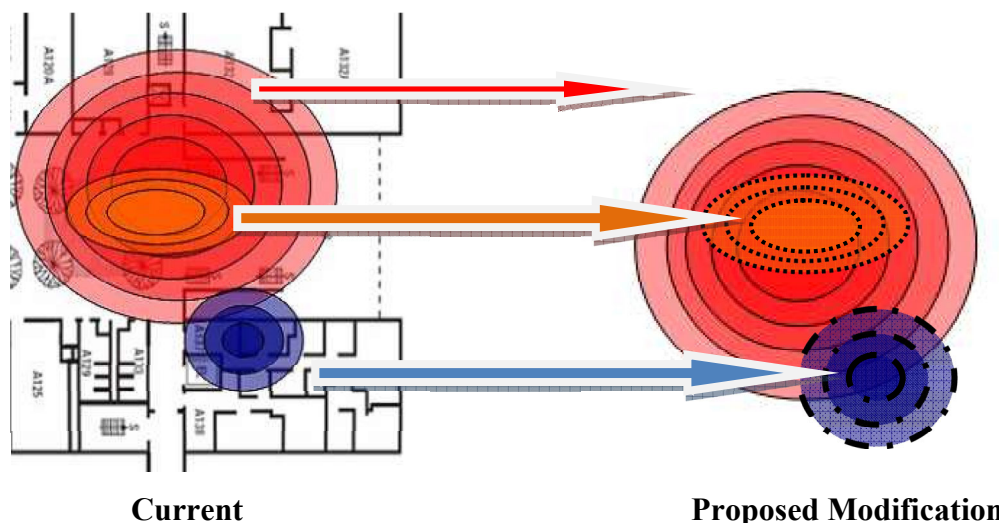


Figure 6.6: Combined Use of Colours and Other Form of Graphics

- b) Consistent use of colours, symbols and text together to provide a balanced display of information for both colour blind and officers with a normal vision (Figure 6.7).

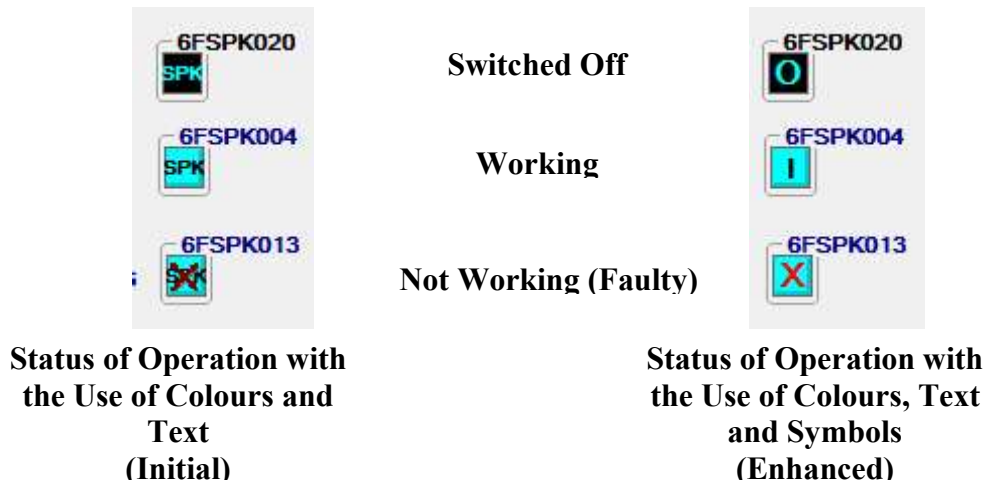


Figure 6.7: Consistent Use of Colours, Symbols and Text Together

- c) Carry out further investigations to identify what form of colour blind deficiencies are common in FRS and identify suitable colour combinations appropriate for the use of both colour blind as well as the officers with normal vision.
- d) Provide higher-level end-user customization where colour blind officers are provided with a formatting option of colours and lines to define and customize their own colours and lines of the symbols that use to display hazards or any other contextual item. One example would be to allow end-users to customize the colours and the lines of the circles in the context guide. This allows the end-users to have their choice of colours, line styles and line thickness when display the contextual hazards such as temperature and flame.

Limitation 7: Inconsistencies across Different Interfaces

Participants expressed their concern about some inconsistencies in the display of similar information in different interfaces belonging to a particular job role. One of the main concerns was related to the interfaces of ICs, where participant feedback clearly indicated the need of consistency when symbols are used to display the working order of resources. In some interfaces, both colour and additional symbolic notation such as a cross on top of the symbol was used to indicate an unusable resource. However, in some of the remaining interfaces a similar condition was displayed differently with the use of colours along with a written comment such as *Not working*. This inconsistency confused the end-users and may

lead to unwanted system complexities. Participant feedback confirms that it is an important goal for designers to maintain consistency among different interfaces.

Proposed Improvement

To minimize the inconsistencies, it is now proposed to use a cross on top of the symbol representing a particular resource throughout all the interfaces, instead of mentioning the working status in writing. Apart from this specific inconsistency, participant feedback indicated possible other inconsistencies in use of colours, symbols, and abbreviations. Therefore, it will be important for the system designers to identify any remaining inconsistencies and to introduce some suitable modifications to make the system interfaces more consistent and therefore, to have standardized functionality, look and feel across interfaces.

Limitation 8: Inappropriate Use of Measuring Units and Terminology

According to feedback received, two specific design failures, which cause SA failures due to erroneous mental modal, were identified. These are as follows:

- The measuring unit used to indicate the hydrant pressure does not match with the unit used in the FRS.
- The term used to demarcate important boundaries *Zone* does not match with the terms used in the FRS.

Proposed Improvement

Feedback received in ten evaluation sessions recommended that the unit BAR instead of PSI to be used for hydrant pressure and further to use the term *Cordon* instead of *Zone* when demarcating the external boundaries. It is further recommended in almost all the evaluation sessions to investigate the remaining abbreviations used in the mock-ups to avoid any other mismatches.

Limitation 9: Inability to Access Critical Information Rapidly

According to the participants, a particular hazard, resource, firefighter, casualty, property, environment or any other similar element or item located on the incident ground may be associated with several pieces of information. However, among them a few pieces of information can become very important or crucial. Participants across all four job roles indicated the importance of identifying the most prominent pieces of information attached to the items or elements located on the incident ground. They recognized the importance of displaying them on a single layer or screen. Maintaining such crucial information in several

different layers may lead to unnecessary system complexities and therefore, end-users may need additional effort and time to locate them. This may cause significant delays in the decision-making process. Hence, as a systems designer, it is important to identify the most crucial and important pieces of information attached to an item or an element located at the incident.

Proposed Improvement

As an example, the most important information related to the hydrants can be displayed on a single information layer rather than split over two different information layers (Figure 6.8). Currently, end-users have to call up secondary layer by clicking on the hydrant symbol to reach the hydrant diameter and its water pressure. But according to the participants, both the diameter and the hydrant pressure should carry the equal prominence similar to the symbol of the hydrant and its reference (BW03).

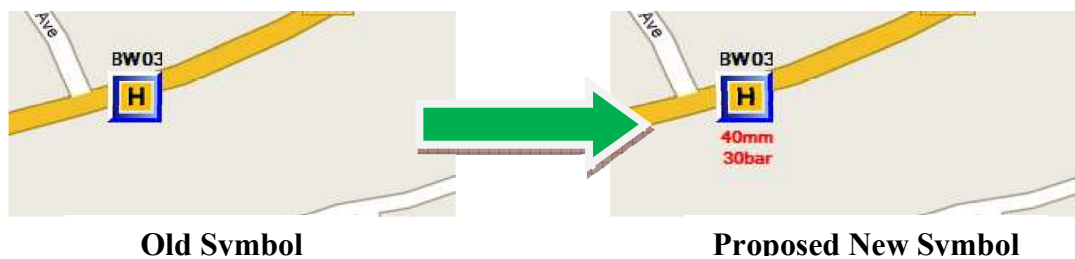


Figure 6.8: Symbol Proposed for Hydrant with added Information

Therefore, all four pieces of information should be displayed on a single screen. Thus, it is recommended that developers should identify the most critical information related to other items and elements and map them onto a single layer of information.

Limitation 10: Displaying of Alarms Inappropriately

Participants indicated the challenges to be faced in incorporating alarms onto the visual display of a moving BA Wearer. Furthermore, the feedback emphasized the importance of avoiding the sudden appearance of a visual alarm irrespective of the display device to be used. Whether it is voice or visual, alarms without any warning can cause a sudden shift in attention of the end-user. This was explained by several examples of possible disasters that may occur due to a sudden change in mental focus. Instead of sending a full length voice alarm without warning, participants of the seven evaluation sessions out of nine related to the job BA Wearer preferred receiving a pre-alert either in the form of a vibration or voice.

Proposed Improvement

It is proposed to use a pre-alert, which could be a voice or vibrator or combination of both at the beginning of an alarming condition. For example, as practiced in Leicestershire, at the *Time of Whistle*, BA Wearers get a sound of an intermittent whistle together with the vibrating air pressure gauge. This tells BA Wearers that their air level has reached the level of whistle. This arrangement currently works well as firefighters are always trained to look at the gauge when they receive the alarm (Catalogued Field Note Ref. 4.2, Appendix 6.5). Similar to this, it is proposed to have a vibrating earpiece speaker with an intermittent *beep* sound as an alarm pre-alert. Thereafter according to the preference of the end-user, he/she could either select a voice or visual display to acquire further information related to that particular alarm. Hence, immediately after receiving the pre-alert, the BA Wearer will be able to use a simple voice command either to hear the actual alarm verbally or to display it visually onto a display device. The option of selecting the delivery mode of the actual alarm should be embedded as a system preset, which can be changed according to the preference of the end-user. At the end of receiving an alarm, the end-user will have the opportunity of either acknowledging the alarm or acquiring more details of the alarm via an appropriate visual display. These changes should minimize firefighters from suddenly shifting their physical and mental attention away from their current tasks.

Limitation 11: Use of Icons and Symbols

It was recognized as important to have a comprehensive collection of icons or symbols representing various hazards, risk, resources and many other information. The feedback also indicates the importance of providing a facility for the end-users to manage the icons on their own. This seems to be crucial as symbols representing risks hazards or others can change with time. Also, there is a possibility of introducing icons related to new hazards, risks or many other useful elements.

Proposed Improvement

It is proposed to introduce an additional interface, which provides the facility of adding new symbols to the existing symbols or icons library of the system. At present, these various fire and emergency related symbols are available in various software file formats such as JPG, GIF, etc. Hence, this new interface must be capable of handling as many file formats as possible. This will allow the end-user to enhance the flexibility by adding new symbols and icons to the default symbols and icons library of the system. In addition, it will be very useful for the end-user to have an option to draw their own symbols representing new

hazards or any other events. This will be a very useful tool, especially for the staff members who are responsible for maintaining operating procedures and risk assessment documentation such as CAT 3 and CAT 4 related to high-risk infrastructure.

Limitation 12: Limited Access to the Data Input Interfaces

The feedback received indicated the Data Input interfaces would be useful for the following additional members of the Incident Command hierarchy:

- Members of the Command Support Team
- Officers at the Command and Control
- Officers supporting SC (such as Safety Officers)
- Officers who prepares risk related documentation (CAT3 and CAT4) for high-risk premises

These job roles need appropriate access to the input screens so that they can also contribute to the richness of the available information during an incident.

Proposed Improvement

It is proposed that the end-users in supporting job roles are viewed as useful and versatile source of information during crisis management. Therefore, rather than being focused just on mechanical sensors it is important to provide appropriate input opportunity for these human sensors (Maris and Pavlin, 2006). This improvement will proportionately enhance the SA of the job roles of IC, SC, BAECO and BA Wearers.

6.3.5 Other Important Findings Useful for Future System Development

Apart from the feedback related to the negative or positive aspects of the mock-ups developed, transcript fragments also revealed few general themes supported by the feedback of more than 75% individual and group evaluation sessions. Findings related to these themes are considered to be very useful during the development of ISs for the firefighters and therefore discussed in detail as follows.

Finding 1: Success of the Method of Information Requirements Capturing

The participants indicated their satisfaction with the method used to capture their information needs. More than 90% of the participants, who had some previous experience of this study, agreed that success in information capturing during the early phase of this study has significantly contributed to the successful development of the mock-ups.

As described in Chapter 3, although there were many other similar CTA tools such as GDIA, ACTA, and HTA, one of the drawbacks of such CTA tools was the limited knowledge in relation to their validity, reliability and usability (Militello and Hutton, 1998). According to Shepherd (2001), it is unclear whether most of the CTA techniques are capable of translating their findings in a systematic and useful way. Apart from a few studies such as assessing the usability and usefulness of the method of ACTA (Militello and Hutton, 1998), there is very little evidence on whether the CTA based methods manage to capture the requirements as expected. Although the demonstration sessions did not compare the use of GDIA against any other requirements gathering tools, the feedback during these sessions provides a clear indication that as a CTA tool, GDIA captured the information requirements of firefighters successfully. Therefore, the feedback justifies the use of GDIA as a tool of requirements gathering in the design of an IS in the domain of fire ER and in other similar domains.

However, several specific pieces of information identified during the application of GDIA as useful was recognized either as not useful anymore or not suitable to display. These comments are significant as they were made by some of the participants who participated in both the GDIA and mock-up evaluation processes. For example, participant for the evaluation Session 6 also participated in the GDIA validation session. These participants stated that although they tried to describe their cognitive needs during the requirement elicitation process, in reality they have never used the support of an IS to access some of such information. Therefore, in such a context, there is always a possibility of expressing some requirements, which may not be feasible to present via an IS. In contrast to the initial requirements gathering, after viewing the mock-up interfaces proposed, they can decide on information presentation in a more realistic context. The following evaluation fragment of the participant of the Session 6 confirms this reasoning.

.....This evaluation session is important also for us to realize some of the information we have validated during our previous meetings is not actually appropriate to display or display of such information could create confusions we never did think during our interviews.....there is a saying seeing is believing. so you realize such complexities only when you actually see the system of delivering such needs....that is what you have developed actually ...something to get an idea how we are going to get our information in what format on what type of display.... when you see all you can suddenly realize some needs previously identified is not necessary or not appropriate to display....

Thus, realistically systems designers should expect some changes to the initially identified information needs when end-users see that information in a context closer to its actual state of presentation.

Finding 2: Importance of Developing Early Prototypes

According to Endsley et al. (2003b) and Maguire (2001a), if the changes required to the design of a system are recognized only at the last phase of a system development when the user interface is developed, it can become quite expensive and difficult to modify. Hence, apart from identifying information needs, it is essential to verify and validate how these information needs should be delivered and presented. The feedback received in more than 80% of the evaluation sessions reinforces the importance of developing an early mock-up during the development of an IS, especially when there are no previous systems to benchmark or currently, there is a lack of systems support. Several participants including the two command support teams of both Leicestershire and Derbyshire clearly identified the importance of developing an early prototype in the form of interface mock-ups. According to them, some of the previously identified information needs may need some modifications when seen in the context of the presentation or delivery mode. It is realistic to expect some changes to some of the previously identified information needs as when end-users see that information in a context closer to its actual state of presentation. Thus, development and evaluation of interface mock-ups can play a bigger role in validation or verification of information to be presented via human computer interface.

Finding 3: The Most Essential Information for Fire ER

Nearly 90% of the participants stressed that the most essential information for the firefighters during the early stage of the fire is to support the *possibility of locating trapped casualties inside a building*. Many ICs wanted something that can provide some information related to trapped casualty inside a building. According to the feedback, any such information will make a dramatic change to the performance levels of fire fighting operations. It will also have an impact on the safety of fire crews as well, since there had been many instances where ICs have made the completely wrong decision of committing firefighters to the building on fire due to non availability of casualty related information.

Similarly, feedback received in more than 80% of the sessions indicated that a system capable of providing dynamic information related to the location of casualty, as the incident

progresses, would have a major impact on the performance of the frontline firefighters. The following points related to locating casualty were mentioned by several participants:

- There are instances where firefighters have to leave the casualties in a relatively safe place so that later a newly deployed crew will be able to rescue them safely. In such circumstances if a device capable of providing location information to the newly deployed firefighters could be attached to the body of the casualty, then it would minimize the time for searching and reaching the casualty again.
- It would be very much useful to attach a sensor device to elderly disable or critically ill people in hospital wards or care homes capable of transmitting location information dynamically during a rescue operation. If such proposal is feasible, then the system can save more lives than ever before.
- It might be possible to use mobile phones and car parking tickets as sources of locating casualty in large shopping malls. Most of the firefighters agreed that there are ethical issues related to such location tracking. But participants believe that if the choice of selecting such facility can be given to the general public, and by educating them with how they can be benefitted during an emergency situation; there could be more positive response.

Almost all the participants were excited about the feature *location tracking of fire fighters*, which provides the location of firefighters who are deployed internally and externally in the fire grounds. Participants described this feature as the best support a system can provide to improve the safety of a firefighter.

More than 75% of participants across all four job roles thought that if a system can at least indicate average temperature or smoke levels of various compartments of a building, that itself makes a dramatic improvement in the planning and decision-making. Similarly, confirmation of detecting a flame can make a significant decision-making improvement. This is not limited to a particular job role but can be crucial for all the members of the IC hierarchy.

In summary, the participants confirmed some of the most critical information that systems supporting firefighters should consider as a priority to enhance the firefighters' SA. Thus, the above points should be considered as essential input for future research purposes if the technology to support firefighters during their response operations in much useful manner. This suggests the need of some focused research in the areas of 1) Casualty Detection and

Tracking, 2) Firefighter tracking and 3) Detection of contextual hazards: Temperature, Smoke and Flame.

Finding 4: Importance of Supporting to Minimize “Response Time”

Participants explained that if IS could support in minimizing “response time” to an incident it could improve the effectiveness of the rescue operations and could further reduce the number of fatalities. The time between the FRS receiving the first call to an incident and the arrival of the first appliance at the scene is defined as the “response time” (CLG, 2009e). According to the feedback, “response time” has increased significantly over the years. These views are confirmed by the House of Commons select Committee's Report on the Department for Communities and Local Government’s Annual Report 2007 (2007). There are several reasons for this (CLG, 2009e). Most of the participants mentioned urbanization and increase of traffic as one of the reasons. Participant’s feedback indicate that it is important to provide real-time and forecasted traffic related information to the firefighters both on and off the incident premise appropriately; starting from the receipt of 999 call and throughout the response operations. Participants thought that the interfaces proposed in this study to display the traffic related information could improve the response times.

Finding 5: Importance of Sending Contextual Information to the Control Room

Participants also explained that in addition to improving response time, it is also crucial to minimize the delay between the time of the start of the actual fire and the mobilization officers at the control rooms issuing advice for initial mobilization of resources. Participants suggest that the need of increasing the decision-making speed at the control room related to early detection of fire is very much crucial. According to them, it is more important than reducing the response time. Current average response time of the UK FRS is approximately around 7 minutes. According to the participants, even if FRS could reduce that time to zero the number of fatalities could be still very high when first fire engine arrives at the scene. Therefore, it is more important to detect the fire as early as possible in the control room, so that mobilization of resources could be expedited.

At present, mobilization officers in the control room have to wait until they have received an accurate 999 call. However, even after the receipt of a 999 call decision-making related to the initial mobilization is often delayed due to the increased number of false alarms. The time from the receipt of the initial 999 call to the initial mobilization is often significant

since officers who make the decision to mobilize try to make sure the information they received is accurate prior to issuing the mobilization alert. According to the feedback, this could be too late to save potential lives. This argument is confirmed by the House of Commons select Committee's Report on the Department for Communities and Local Government's Annual Report 2007 (2007). It indicates that it is not only adequate to merely reduce the response time, because at present around 80% of the overall deaths predicted at fire incidents have happened at the point at which the officers in the FRS control room first received the 999 call. This clearly indicates that if officers at the control rooms could be supported with the information to detect the fire early, it could have a direct impact on reducing the high-level of fatalities. In such situations, participants suggested that it would be helpful to provide information related to the basic hazards such as temperature and flame directly to the control room.

Most of the participants thought it could be similar to the "Dash Board" interface proposed for the ICs. This interface should be able to generate suitable alarms capable of detecting rapid variations of temperature and flame. Participants believed that this type of interface may crucially support mobilization officers to detect a fire much earlier compared to the current situation and speed-up the decision-making process at the control room to issue very early mobilization advice. Participants believed that support to detect fire very early at the control room by providing access to proposed type of system could have a significant impact to reduce the number of casualties and deaths at the incident.

In addition, a report on the emerging issues arising from the fatal fire on 3rd July 2009 at Lakanal House, a multi-story community condominium in London (CLG, 2009f), has strongly recommended providing a link between the individual dwelling or compartments of the buildings and the control room, ensuring prompt and accurate call to the FRS. In this report, the Chief Fire and Rescue Adviser stated that such a system could also allow for a manual predetermined delay of the call transmission to prevent unwanted false alarms. Thus, in addition to expedite the mobilization, this solution could also indirectly help to minimize the number of false alarms received at the control room.

The idea of sharing contextual information related to the incident site with the officers located in the control room also complements most of the previous research efforts on large-scale natural and manmade emergencies (Potter et al.,2007), Fire Emergencies (Berry

et al., 2005) and Forest Fire (Avesani et al., 2000). These recognized the importance of linking the command and control centre and the incident premise during an emergency. In the case of FRS operations, clearly it is an advantage to have incident related information available to the control room before it receives a 999 call or automatic fire alarm from a high-risk fire sites. Therefore, it is recommended that the systems should consider providing an uninterrupted link so that the control room can continuously monitor and access the contextual information, at least for the high-risk fire sites. This proposal also shows how enhancing SA of the members away from the incident premise can improve the overall performance of a fire ER operation.

Finding 6: Importance of Recognizing the Differences of SMEs in Developing ISs for Firefighters

Transcript fragments used for the *Limitation 1: Organizing the Information around the Goals of an End-user* in Section 6.3.4 also shows that it is not only the number of years of service, but real-life practice and relevant recent experiences should also be considered determining whether a SME is a novice or an experienced. Thus, it is important to recognize these differences in SMEs in developing ISs for firefighters. It confirms the importance of obtaining the needs of both novice and experienced officers in IS design and development efforts. This suggests the following principles for selecting SMEs for the process of IS design and development.

- Select participants in the range of having less years of experience to many years of experience.
- Select Participants from both full-time staff and part-time staff (retained).
- Select Participants across the range from less experience to many years of experience in particular type of incidents for which the system aims to support.
- Select Participants across the range of having recent experience to not having recent experience in a particular type of incidents for which the system aims to support.

Finding 7: Level of Accuracy of the Information

The accuracy required for a piece of information can be different from job role to job role and type of operation. For example, as explained by several participants, in the early stages of a fire incident, more than the accuracy of the location of the casualty it will be important for an IC to know whether there is any casualty inside the building. However, the accuracy of the casualty related information required for a BA Wearer deployed for a casualty rescue

mission expects a much precision location of the casualty. Furthermore, in normal circumstances, for an IC it may be useful to know at least in which floor the firefighters are located rather than their exact location and movement. However, in the case of supporting the frontline firefighters to navigate them inside a building, accuracy of the location information should be very much higher than the previous situations.

6.4 Summary

In this chapter, feedback obtained during the mock-up interface demonstration sessions were analyzed into various themes. For each theme, based on the participant's feedback, the chapter has presented findings for evaluating or improving the performance of the proposed system. These findings have considered the relevance of SA Demons and their impact in relation to the system proposed for presenting information to firefighter to enhance their SA during fire ER. The findings have also considered the appropriateness, usefulness of the human computer interfaces proposed. Furthermore, findings have explained some specific strengths and weaknesses of the mock-up interfaces proposed for four firefighter job roles. Having considered the end-user feedback, chapter has also proposed necessary modifications to overcome identified design limitations and some recommendations to further enhance the strengths already embedded in the interfaces proposed. Thus, the findings related to the mock-up evaluation presented in this study contribute to improve the design and development efforts of ISs that support firefighters during their ER operations. Together with the mock-up interfaces proposed for four firefighter jobs, findings during the evaluation of those mock-ups and further enhancements proposed will provide an ideal platform for designers and developers who face the challenge of developing similar ISs.

Chapter 7 : Information Systems Architecture for Fire Emergency Response

7.1 Introduction

The aim of this chapter is to propose a conceptual Information Systems Architecture (ISA) for a system supporting the fire Emergency Response (ER) to large-scale built environment fires. This chapter begins with a discussion on the design approach and then defines and introduces the layers of the architecture. It is followed by an in-depth discussion explaining the components and functionality of each layer of the architecture proposed. This chapter also explains challenges and opportunities for existing technologies to implement the architecture proposed and recognizes some future research needs.

There is very little literature on the higher-level systems architecture of an Information System (IS) for fire ER; which is well understood by both the owners of the system as well as the systems architects. Most of the architectures proposed are not comprehensive as they focus on a few selected needs of the end-users or a few technologies. More often, they depict only the view of the systems architects and developers. Also, the literature reviewed in Chapter 2 indicates very little evidence on successfully implementing ISs capable of supporting fire emergency responders. Therefore, currently there are almost no means available to understand the essential components of an IS supporting fire ER and their functionality. To overcome these gaps, this chapter defines the conceptual architectural view of an IS for fire ER, which comprehensively addresses the end-user's needs. Importantly, the proposed architecture is not constrained to any particular technologies and comprehensible to the potential system's end-users, the system's designers and architects.

7.2 Approach to Propose ISA for Fire ER

As explained in Chapter 3, prescription of the ISA proposed follows an approach based on the work related to defining a framework for ISA (Zachman, 1987; Sowa and Zachman, 1992). The understanding of the fire emergency context via observations and document references corresponds to the "Planner's View" of the ISA framework of Zachman (1987). This early contextual understanding depicted the basic intent of IS in the minds of firefighters. Thus, contextual understanding has laid the initial foundation to propose a comprehensive architectural view corresponding to the "Owner's View" (Zachman, 1987)

or “End-user’s View.” The ISA proposed in this Chapter is primarily based on the following outcomes of this study:

- The validated set of GDI diagrams consisting of the comprehensive information needs of four firefighter job roles.
- The software mock-up consists of Human Computer Interfaces illustrating the information presentation needs of firefighters and refined in the process of mock-up evaluation.

The ISA proposed primarily focuses on prescribing the three types of conceptual description: *data*, *function* and *network* (Zachman, 1987). During the process of prescribing the ISA, recommendations for suitable technological solutions are made after careful review of their individual strengths and weaknesses in light of the above outcomes. The gaps within currently available technologies, which are limited in providing end-user requirements, are identified.

7.3 Information Systems Architecture Proposed

As explained in Chapter 2, there are several attempts to develop ISAs to exclusively support the ER operations. Madey et al. (2006) developed a Wireless Phone Based ISA to provide traffic forecasts and emergency alerts for engineering, public safety and ER personnel. However, the scope of this architecture is limited to the technological capabilities of mobile phones. These also include “WORKPAD” (de Leoni et al., 2007), a layered communication architecture to support decision-making during ER operations. This architecture consists of a Mobile Ad-Hoc Network (MANET) based Data Storage & Communication Layer, a Middleware Layer for the management of various emergency related dynamic process, and User Layers to support two types of users to interact with the system. As explained in Chapter 2, this architecture is aimed to support the needs of the operators who are acting directly on the field during disasters. There is no evidence to justify that this architecture addresses the individual needs of different type of responders.

Moreover, Meissner et al. (2006) presented an integrated mobile information and communication systems architecture: “MIKoBOS” for ER operations. This architecture concerns reliable data communications within the emergency site as well as between the site and the headquarters. As explained in Chapter 2, this architecture is focused on some

common needs of emergency personnel working at the command centres, emergency operation commanders working inside vehicles located at the incident and frontline responders roaming around the incident. It consists of four layers. At the top of the architecture is the *Application Components* layer, consisting of the application components supporting the needs of three types of end-users. Immediately below is the *Functions Modules* layer, consisting of function modules common to all three types of end-users. Next is the *Basic Services* layer, consisting of essential basic services supporting other components of the architecture. The bottom layer is the *Networks* layer, consisting of essential networks required to support the communication needs of three types of end-users. Also, this architecture describes and compares technologies suitable in developing the communication network for different types of users. Importantly this particular architecture is based on the study by Fraunhofer Gesellschaft (Fraunhofer-Gesellschaft, 2007) in relation to the needs of end-users of disaster and emergency management systems (Meissner et al., 2006). Therefore, it reflects the actual requirement of the end-users belonging to the emergency related domains. The “MIKoBOS” architecture is unique as it identifies the essential need of presenting information to the system end-users in an appropriate format as responders with different roles may need different types of human computer interfaces and display devices depending on their work behaviour and context of operation. It acknowledges the importance of having a multilevel distribution of the application, depending on the organizational structure of emergency services and the nature of disaster response. However, as explained in Chapter 2, the architecture proposed only address the needs that are common to generic emergency situations. Therefore, it may not comprehensively represent an ISA specific to supporting a particular type of emergency or responders of a particular type of emergency service.

Apart from the above explained generic ER ISAs, there are also some ISAs that focus on supporting a particular type of emergency conditions or domains (Kwan and Lee, 2005; Hwang et al., 2007; Lorincz et al., 2004). However, none of this work directly supports response operations of the Fire and Rescue Service (FRS).

In contrast to the above work, the work of Wilson et al. (2005) and Wilson et al. (2007) on the “Fire” project, Jiang et al. (2004a) on the “Siren” project, Jiang et al. (2004b) on the Large Displays for ICs and Klann (2008) on the “LifeNet” project are significant efforts in developing firefighter related ISs. All these systems support the fire ER operations in built

environments. However, these works did not focus on the systems architecture, but were focused on the actual prototype or product development limited to single or few needs of firefighters. Therefore, these previous works are very much less comprehensive in describing the architecture of an IS supporting fire ER. The conceptual systems architecture proposed by the “FireGrid” Project (Upadhyay et al., 2008) appears to be the only significant architecture, which exclusively supports the response to fires in built environments. The high-level architecture proposed for the “FireGrid” includes the sample components, the data and control connections. It highlights the integrating nature of various technologies and the distributed nature of the architecture. Although this architecture recognises the diverse needs of technology to capture the contextual information, it does not identify the technological diversity required for the successful presentation of information to various types of firefighters. Furthermore, this architecture does not reflect the possible Human Computer Interaction (HCI) differences due to the differences of the firefighter job criteria, their behaviour and context of operation. Therefore, the architecture proposed is not fully capable of addressing the different needs of different firefighter job roles.

Regardless of the ER domain, all the architectures reviewed above depict the characteristics of the “Owners View” of the Zachman’s (1987) ISA classification. From the review, it can be concluded that most of the proposed architectures recognize the importance of having integrated technologies and systems in supporting ER. However, most of the proposed architectures are only concerned with the technologies in relation to the information capturing and its transmission. They rarely identified the technologies related to the presentation of information to various types of end-users. While most of the ISAs supporting generic emergencies only focus on some common needs during an emergency, most of the previous work specifically related to fire ER concerns only a few selected needs of its end-users. There is no evidence of an ISA that supports the comprehensive needs of different firefighter job roles.

The above discussion clearly indicates the lack of a comprehensive ISA addressing the needs for supporting fire ER. To make things worse, currently there is very little evidence available on a successfully implemented IS supporting firefighters. This lack of understanding could become one of the major constraints for the firefighters, the FRS and the system architects and designers to carry out meaningful discussion during the process of

developing ISs to support firefighters. This could lead to slowdown in the progress of implementing support systems for firefighters and to develop ISs, which may get rejected by the end-users. These limitations led to prescribe an “Owner’s View” of an ISA exclusively supporting firefighters during their response operations. Having compared the capabilities and capacity of previously presented ISAs in light of the specific needs identified for different types of fire emergency responders, this study proposes an ISA consisting of four layers: 1) Data Capture & Networks, 2) Data Manipulation, 3) Function Modules and 4) Human Computer Interaction (Figure 7.1).

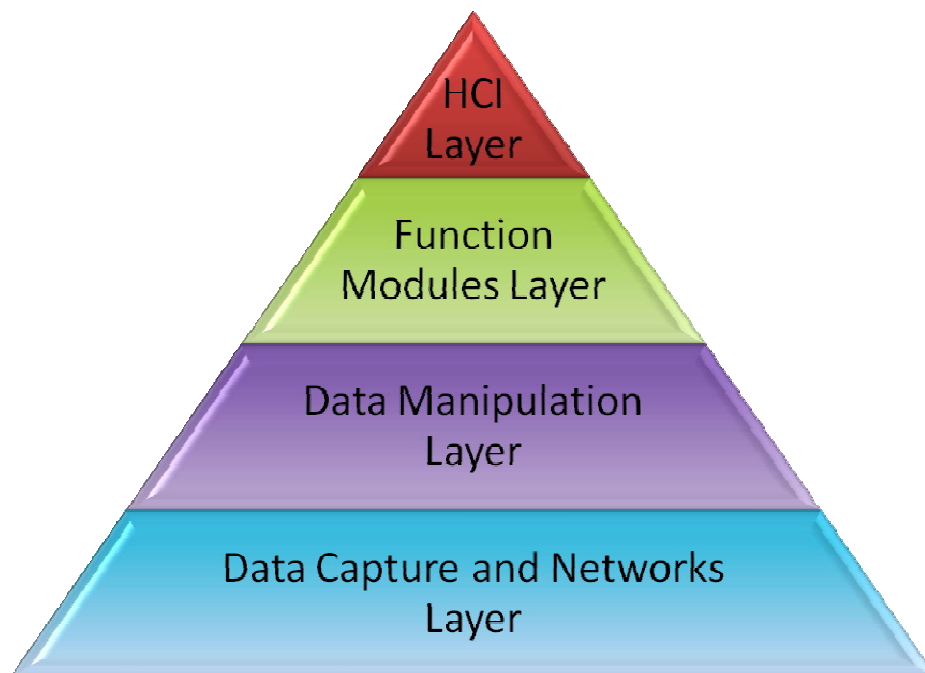


Figure 7.1: Primary Layers of the ISA Proposed for fire ER

Data Capture and Networks Layer of the architecture will look after the capturing of data from various information sources and means of communication between information sources and other components of the architecture.

Data Manipulation Layer of the architecture will look after the services that add value to initially captured data from various sources.

Function Modules Layer of the architecture will look after organising information to perform various common functionalities expected by the different end-users.

Human Computer Interaction Layer of the architecture will look after the functionality of various human computer interfaces supporting different firefighter jobs that could be deployed via appropriate human computer interaction devices.

Importantly, the composition and functionality of each layer of the architecture proposed is defined after considering the following implications specific to the context of this study:

- Identified end-user information needs.
- End-user information presentation and sharing needs.
- Existing opportunities and challenges for proven software and hardware technologies to look after the above identified end-user requirements.
- The new software and hardware technology requirements generated due the limitations of currently available technologies.

7.4 Data Capture and Networks Layer

At the bottom of the ISA is the Data Capture and Networks layer. This layer is concerned with collecting data from a wide variety of sources, a range of different networks to which these sources and end-users of the system are connected and a common communication service to connect different types of networks. Essentially, this layer builds the communication infrastructure of the IS. The data collected in this layer are passed onto the Data Manipulation layer for the initial processing. When consider various needs of firefighters identified in previous stages, data capturing requires the input of both electro-mechanical and human sources; especially the information input of different type of firefighters. It is crucial to capture these information needs from many different types of information sources located in and around the incident premise, and maintain communication among 1) various contextual information capturing devices, 2) different types of firefighters located inside and outside the incident premise, 3) display devices proposed for the use of different firefighter jobs fixed inside the fire engines and various locations in the incident premise, 4) FRS control room, 5) fire stations, 6) information sources belong to other support services such as ambulance service, police and the local government and 7) third party information sources such as weather, media and traffic.

Having considered the above discussion, the Appendix 7.1 explains a conceptual data capturing and communication network suitable of maintaining the identified communication needs of the proposed IS. It is concluded that there is no single communication technology that fulfils the requirements of the end-users of the proposed ER IS. In fact, the question of level of network redundancy available for the firefighters was one of the important issues raised during this study. This is justified by the following

frequently raised questions by the firefighters: 1) *Is there a backup if the proposed communication hierarchy is disconnected?* 2) *Do you have an alternative means of communication if the existing one fails?* 3) *If all the things fail can we still switch to our usual two way radio communication?* As a consequence, it will be more appropriate to use a network architecture supporting multiple communication technologies simultaneously. By integrating various technologies into one platform and by using them flexibly and interchangeably, the various communication alternatives can complement each other. If one network is unavailable, the system can switch to use another available option. Preferably, the switch between different technologies can be done automatically according to predefined policies (Meissner et al., 2006). In this way, an acceptably high availability of communication can be guaranteed without incurring extensive unnecessary costs.

Based on these considerations, this study proposes a high-level architectural layout for the data capture and networks layer as shown in Figure 7.2. It shows the connectivity of various different networks identified as suitable to form the data capture and networks layer of the IS. The success of the IS proposed will largely depend on the ability of various network platforms to work in combination to form heterogeneous networks consisting of various types of sensors and protocols. If this cannot be achieved, it may seriously hinder the feasibility of deploying the type of IS proposed. To maintain communication between various heterogeneous networks and to transmit data across different networks, it is decided that IS proposed should have an extensive support of a common communication service that should run on top of all the networks. This communication service makes a common tunnel, independent from the network, whether it is IP based or RF based and is connected through different types of terrestrial or non-terrestrial communication technologies. This service should run across all the technologies that have been discussed so that the data from various sources could be processed with the use of other services and later to be passed on to the next level of the architecture.

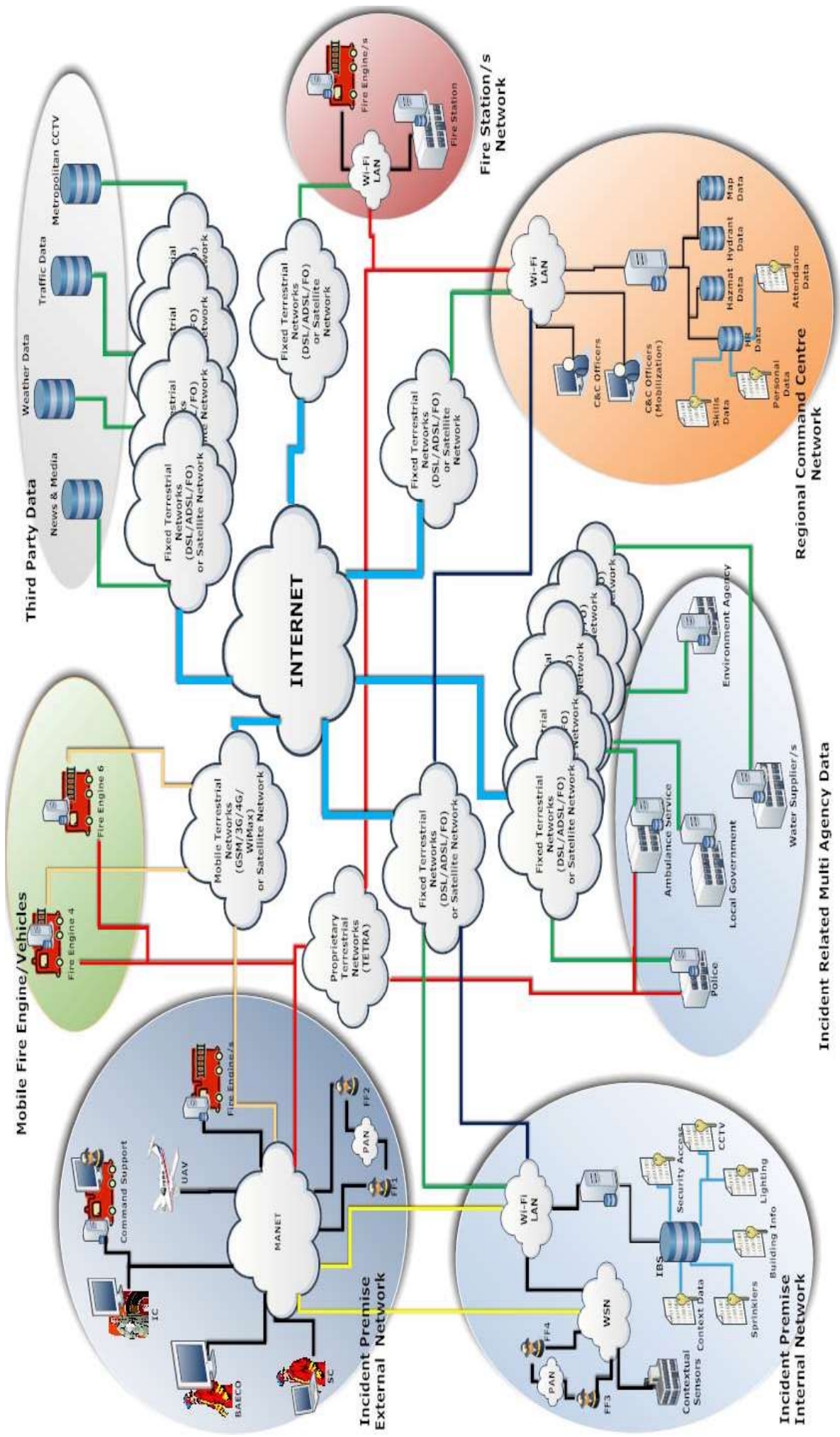


Figure 7.2: Data Capture and Networks Layer of the ISA

Therefore, networks communication service is important as it provides a consistence interface between other upper level modules of the architecture by transporting data regardless of the differences of underlying networking technologies, networking protocols or communication technologies. The networks communication service takes the responsibility of converting data to a compatible format so that it can be transported across multiple technologies. This is also responsible for alerts of communication status changes, bandwidth allocation management and adapting the data stream to available communication conditions according to associated policies like priority.

7.5 Data Manipulation Layer

The data captured from sensors and various other public and proprietary databases attached to various types of networks is passed up to the next layer labelled as the Data Manipulation layer. This layer is concerned about providing the support services necessary to carry out common data manipulation such as storing, filtering and processing so that more value added data can be passed on to the next layer to carry out higher-level functions unique to fire ER. To carry out such services this study proposes following as the main constituents of the Data Manipulation layer of the ISA proposed:

- Data Management
- Data Fusion
- Method/ Model Base

The following sections explain the reasons for the selection of each of the above service and their uses in implementing the Data Manipulation Layer of the ISA proposed.

7.5.1 Data Fusion

There is a need for data fusion for an IS supporting firefighters, because data related to the same element or entity may come from different types of human and mechanical sensors (for example data on casualty) and from spatially dispersed data sources. Although it is not directly related to fire emergencies, there is some emergency related research listed below which justifies the use of data fusion as one of the major architectural component of the IS proposed. This research includes the following:

- Scott and Rogova (2004) proposed a design of a fusion system for data rich, knowledge poor environment following a natural disaster, comprising of heterogeneous information sources.

- d'Agostino et al. (2002) describe their efforts into the design of tools to monitor the situation after a large-scale disaster, with a particular focus on the task of situation assessment and high-level information fusion.
- Solaiman et al. (1999) describe the use of information fusion during a medical emergency.
- Llinas et al. (2002) identifies the use of information fusion and describes useful fusion techniques that offer promise for realizing high quality information demand in nuclear, chemical, biological and radiological battle management.
- Maris and Pavlin (2006) and Pavlin et al. (2004) recognize the use of information fusion to support the crisis related management applications.

Since the system proposed in this study aims to enhance the firefighter SA, it is important to carry out data fusion in such a way that it promotes SA. The need for data fusion for Situation Awareness (SA) in multi-sensory data capturing contexts has been identified by Salerno et al. (2004). According to Salerno et al. (2004), over the years, more than thirty fusion models have been proposed. However, no model has become as influential in data fusion as the JDL model (Hall and Llinas, 1997). Salerno et al. (2004) recognized the complementary nature of JDL model in relation to the SA model of Endsley (1995), and described the JDL model as the most appropriate functional model for data fusion to complement the SA in complex domains. JDL model proposes to carry out data fusion in three increasing levels of inference (Hall and Llinas, 1997). Level 1 fusion is defined as the "Object Assessment". This process combines locational, parametric data, and identity information to achieve refined representations of individual objects. Level 2 fusion is defined as the "Situation Refinement." This level of the fusion process develops a description of current relationships among objects and events in the context of their environment. At this level, distributions of individual objects defined by Level 1 fusion process are examined to aggregate operationally meaningful comprehensive units. Finally, Level 3 fusion is defined as "Impact Assessment" where this level of the fusion process projects the progress of the current situation into the future. Having considered the output of the Level 1, Level 2 and Level 2 data fusion of the JDL Model, Blasch et al. (2006) identified its close corresponds to the Level 1, 2 and 3 SA requirements of Endsley's (1995) SA model.

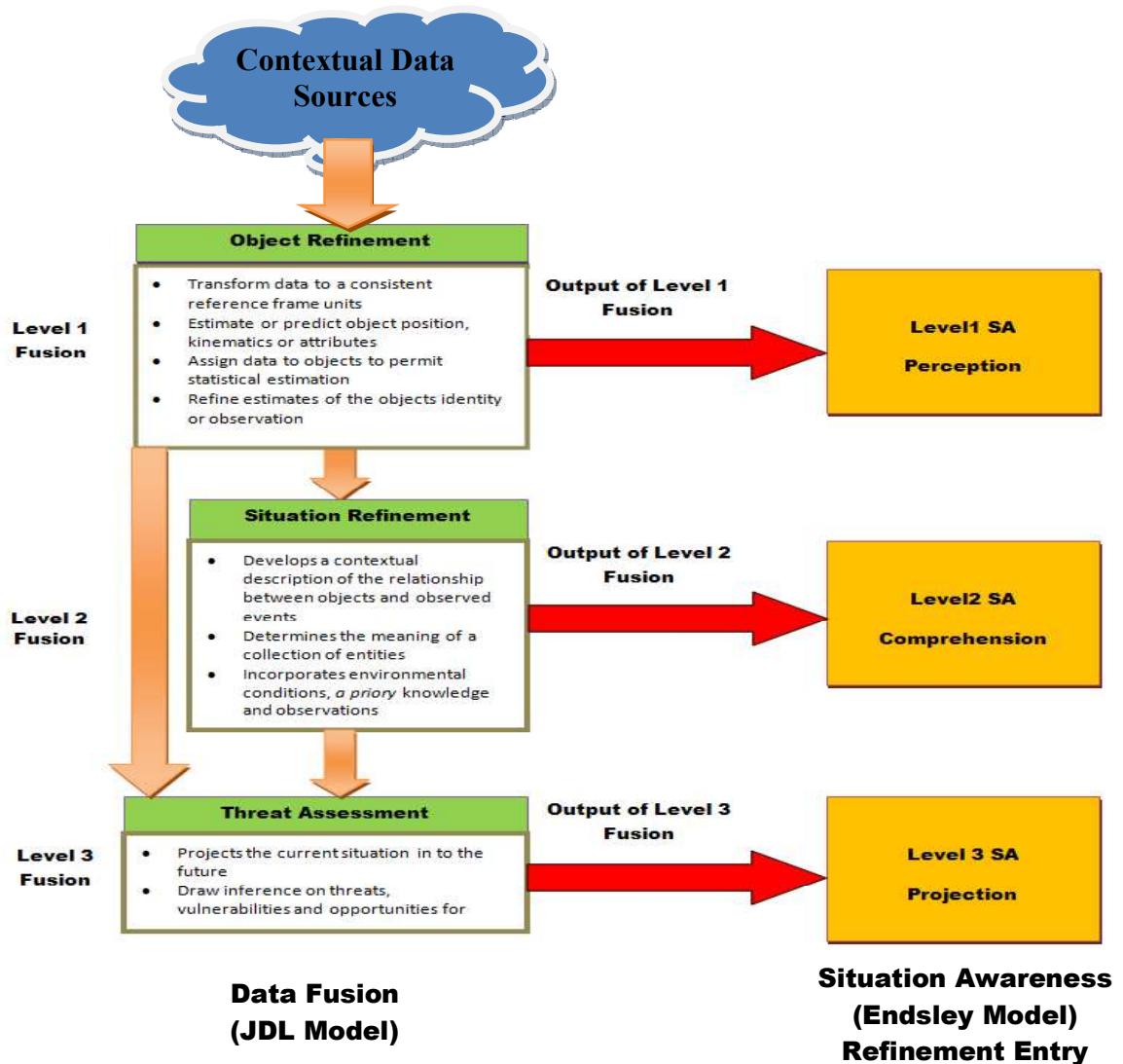


Figure 7.3: Output of JDL Fusion Model Complements SA Endsley Model

As shown in Figure 7.3, the resultant of each fusion stage of the JDL model provides the information corresponding to the three SA levels: Perception, Comprehension and Projection. The resultant information at each fusion level may either be accessed by the higher-level functional modules of the ISA proposed or can be further processed at a higher fusion level with the support of the services of the Method/Model Base to achieve higher inference.

This study has recognized the ability of JDL fusion model to implement the three levels of SA that is essential to support firefighter decision-making during their ER operations. Thus, this study strongly recommends adopting JDL fusion model to appropriately carry out the Level 1, Level 2 and Level 3 data fusion at the data manipulation layer of ISA proposed. The following paragraph explains a conceptual fusion process useful to achieve data fusion

for the proposed IS as recommended in the JDL model.

This study identified the need of ad-hoc sensor networks containing a variety of contextual and location tracking sensors. Such sensor networks essentially require processing of large amounts of heterogeneous sensory data and information from spatially dispersed sources. Traditionally sensory data and other information are processed centrally (Maris and Pavlin, 2006). However, central approaches suffer from inadequate communication and processing capacity and vulnerability to single-point failures. In addition, central approaches to fusion might not be well suited for dynamic systems, operating in dynamic and difficult environment. Centralized fusion approaches require centralized reasoning about the states of the fusion system itself, which can result in massive flow of information and additional processing (Pavlin et al, 2004). Hence, comparatively lower data rates and higher costs prevailing in mobile networks may create severe bottlenecks in centralised data fusion. Thus, this study strongly recommends the need of distributed data fusion compared to centralized data fusion. A distributed fusion system should be able to adapt to the current situation without human intervention, which requires autonomous behaviour; modules should form fusion systems consisting of relevant modules autonomously and they should be able to reason out resource allocation with respect to sensing and processing capacity (Pavlin et al., 2007). To cope with such complex functionality in a systematic way, this study proposes a multi-agent system (Wooldridge, 2009) in which each agent should take care of partial fusion as defined in the work of Maris and Pavlin (2006). Furthermore, considering the data processing capabilities of the modern day sensor motes, this study proposes “tiered” data fusion (Mullen et al., 2006; Chong and Kumar, 2003; Pavlin et al., 2004). Essentially, this tiered fusion network should consist of two types of agents: 1) the *Sensor agents* consisting of both physical and human sensors and 2) the *Fusion agents*, which takes the input from sensor agents and carry out further fusion of information. By adopting the partial data fusion guidance of Maris and Pavlin (2006), the proposed Data Fusion service should be able to combine the support of various *Sensor agents* and *Fusion agents* to fuse the data captured from various data sources and store them in the fusion database. Data sources can be a combination of 1) local sensors associated with a data fusion system (Example: sensors physically associated with the data fusion system or organic sensors physically integrated with a data fusion system platform), 2) distributed sensors linked electronically to a fusion system and 3) other data such as reference information, geographical information, hazmat information, information stored at various

supporting databases and the fusion databases itself, 4) output of fusion agents located at various levels of the tiered data fusion architecture. It is expected that Sensor and Fusion agents appropriately connected in tiered data fusion architecture would be able to fuse the data into three increasing levels of inference as described in the JDL fusion model.

7.5.2 Method/Model Base

This service stores various Methods, Models and Procedures that support various fusion agents to enhance the fusion process. It would be an impossible task for the IS proposed to meet the Level 2 and Level 3 SA needs of firefighters unless data fusion service is supported by the services of appropriate Methods and Models. Thus, the service of appropriate collection of Methods and Models are essential to implement the IS proposed. This service should provide the essential support for :

- The agents to phrase and clean data so that resultant becomes increasingly meaningful.
- Discover new knowledge, predict or alert the end-users by combining the data available in fusion data bases and other support databases.
- Control various functionality of the system. For example, Speech Recognition to control the HMD.

Depending on the information needs of the firefighters, Methods and Model Base could include the services of various algorithms such as Kalman Filters, Alpha-beta Filters, Covariance Error Estimation and expert build models such as Computational Fluid Dynamics (CFD) models for propagation of fire or cloud of hazardous gas. In an actual process of implementation of the IS proposed, it is important to select the most appropriate methods and models, or to develop new methods and models capable of addressing the identified needs of firefighter.

7.5.3 Data Management

The Data management service should be able to facilitate access to, and management of, data fusion databases and all other supporting databases. Data management include the services 1) Data retrieval, 2) Storage, 3) Archiving, 3) Compression, 4) Relational queries, and 5) Data protection. The type of data stored in these databases can be dynamic, static or historic. Moreover, these databases are highly distributed and can be located at:

- The incident premises; related to the IBS and the sensor network.

- FRS's control room.
- Data terminals fixed in the incident command vehicle and fire engines.
- Mobile computers deployed in various parts of the incident ground.
- Any other third party databases containing various supporting information such as traffic, whether, hazmat and HR; located at other remote locations away from the incident.

Database management of the proposed IS will be particularly difficult because of the large and varied data managed (i.e., images, signal data, vectors, textural data) and the data rates both for ingestion of incoming sensor data, as well as the need for rapid retrieval (Hall and Llinas, 1997).

7.6 Function Modules Layer

By combining various basic services in the immediate lower-level layer, modules in this layer should be capable of carrying out the necessary processing required to produce essential functionality at the HCI layer. This particular layer is a transparent layer to the end-users who interact with the system via the HCI layer. This layer should be able to process data to perform various functions in relation to the information to be delivered. Thus, such processed data embedded with various common functionalities could be presented at the HCI layer according to the unique presentation requirements of the end-users representing various job roles. Having considered the end-user needs related to the information, this study proposes the following modules to carry out the necessary processing of the data before it is presented via various human computer interfaces at the HCI layer.

Physical and Human Resource Management

This particular function module should be able to carry out the necessary functions relevant for ordering, monitoring and deploying of both physical and human resources. The physical resources managed by this module range from Dry Welfare Rations, Air Cylinders required for the use of BA Wearers to much bigger installations such as high volume water pumps and decontamination units. Human resources managed by this module primarily include the officers directly belonging to the FRS and who work in designations ranging from the ranks of firefighters, safety officers and chief fire officer of a brigade to regional chief fire

officers of the FRS. Apart from managing human resources directly belonging to FRS, this module should also be able to coordinate the human resources from other organizations such as Police, Ambulance Service attending at the incident premise. It should also look after the functions necessary for welfare and relief of firefighters operating at various jobs. Resource related monitoring should include the functions necessary to locate and monitor the status of various physical resources belonging to the FRS, incident premises and other third party such as water suppliers.

Sector and Cordon Management

This function module should be able to carry out the necessary functions relevant to create, change and removal of the sectors and cordons in and outside the incident premise.

Hierarchy and Job Management

This particular functional module should be able to carry out the necessary functions to build and continuously maintain the incident hierarchy. This module is directly responsible for the creation and management of jobs at different levels of the hierarchy.

Location Tracking and Navigation Management

This module should be able to look after the functions relevant to real-time movement of people, including casualty located in an around the incident ground. Furthermore, it should look after the function of navigation of firefighters. In addition to humans, this module should look after real-time location tracking and routing of various vehicles belonging to the FRS. This module should also be responsible for the location tracking of various assets belonging to an incident premise. This could include assets such as artefacts and valuables in a heritage site or LPG and Acetylene Cylinders in an industrial site.

Context Monitoring

This functional module should look after the functions necessary to monitor the location, movement, spread and levels of various contextual risks and hazards in an around the incident dynamically. In addition, this module should carry out the functions necessary to monitor other contextual conditions such as weather and traffic. This module should also be capable of carrying out necessary functions to monitor the operating conditions and functionality of various equipment, installations and infrastructure located in and out around the vicinity of the incident premise.

In addition to the main function modules, there can be several other secondary modules as discussed below.

Geographical

This functional module should enhance the services provided by other functional modules by acknowledging their requests to generate both 2D and 3D map and terrain information in and around the incident premise appropriately.

Data Input Support

With the support of different types of data input tools and techniques proposed, this sub function module should support the functionality required to satisfy the data entry requests received from the other main functional modules. It should look after the functions necessary for add, delete and editing of various types of data entry related requests.

Alarm/Alert/Message Generation

This module should carry out the functions necessary to generate various alarms alert and messages to enhance the functionality of other main function modules.

Report/Log

This functional module should look after the functions necessary to build and maintain various reports and logs related to the incident. The request for report generation may come from other main function modules.

Importantly, both primary and secondary functional modules either directly support the end-users with the necessary processing or support them indirectly by improving the processing capability of other functional modules. For example, the end-user request related to monitoring of the spread of a chemical plume around the incident building may need the processed output of both the function modules *context monitoring* and *map module*. Similarly, *Sector and Cordon management* module may always need the support of the sub function module *Data input* to carry out the sectorisation requests of end-users received via the HCI layer. These examples indicate that while it is important to have communication with the components of the HCI layer it is equally important to arrange all the main and sub function modules in such a way that each module can communicate with any other main or sub module to entertain the requests generated within the function modules.

7.7 Human Computer Interaction (HCI) Layer

This study focuses on the specific needs of four core job roles of the incident command hierarchy. These four members were selected with the expectation that their needs would represent the needs of the other members of the incident command hierarchy directly or indirectly. Therefore, the HCI layer of the ISA proposed should consist of HCI modules for each of these core firefighter job roles. Module for each job role will comprise of the human computer interfaces specified in Chapter 5, implemented with the support of appropriate technology capable of providing necessary human interaction to access each specified interface. For example, As specified in Chapter 5, HCI module for the job role of IC may consist of human computer interfaces such as Dash Board, Black Box and many other interfaces capable of presenting perception, comprehension and projection level information. Similarly, SC, BAECO and BA Wearer modules may consist of human computer interfaces relevant for each individual job role.

In addition to the four main job roles, in actual circumstances it will be important to provide access to the IS for all other remaining members of the IC hierarchy. Therefore, it is essential for HCI layer to carry modules consisting of human computer interfaces suitable of supporting other job roles of the IC hierarchy (Prasanna et al., 2007). For instance, having considered similarities in the work behaviour, mobility and the working environment, it can be assumed that the HCI module proposed for the IC would be useful for the Operational Commanders. Similarly, it is also assumed that the HCI module proposed for the SC would be useful for various functional and operational SC, Crew Commanders and Safety officers. However, some degree of customization may be required when designing the human computer interfaces for these job roles. Furthermore, the evaluation of the usability of proposed human computer interfaces revealed the importance of providing online access to the following additional members who are directly or indirectly linked to the incident command hierarchy during a response operation.

- Members of the Command Support (CS) Team
- Officers at the Control Room

Members of the CS team are identified as the main support personnel to the top incident command team to manage the information. These members essentially play the role of the human sensors that can input some important information to the system as well as become

one of the system end-users. Similarly, officers at the control room are identified as the essential end-users in the fire detection and in the initial deployment of resources. Moreover, feedback received during mock-up evaluation indicates that if the officers at the control room can monitor the continuous operation, it will further strengthen the response operation at the incident premise. Therefore, similar to the other job roles it is equally important for this layer to carry HCI modules to support these two job roles. Thus, a HCI layer of comprehensive fire ER IS should consist of the following distinct HCI modules:

- IC/Operations Commander
- SCs (Functional and Operational) , Crew Commanders and Safety Officers
- BAECOs
- BA Wearers and other frontline Firefighters
- CS Officers
- Officers at the Control Room

All the remaining firefighter job roles can be assumed to fall into any of the above type when designing the HCI Modules.

The nature of an ER is dynamic and often extreme and therefore, fundamentally different from the office environments, in terms of physical risk, psychological state and operating conditions. Thus, even for the requirements, which are functionally similar, these differences will require different human computer interfaces consisting of different visualization and presentation techniques suitable for the different users. Depending on the end-user's operational environments and their level of mobility, these interfaces may need to configure to run on different hardware platforms with customized functionalities (Prasanna et al., 2007). Having recognized the composition of the HCI modules proposed, the Appendix 7.2 introduces appropriate technological concepts suitable for the deployment of each module so that end-users could maintain necessary interaction during access of various interfaces specified. This discussion also addresses the opportunities and challenges faced by currently available technologies in implementing these HCI concepts.

7.8 Overall View of the ISA

The Figure 7.4 shows a graphical illustration of the overall comprehensive architecture of the IS being proposed and summarises all the points made previously.

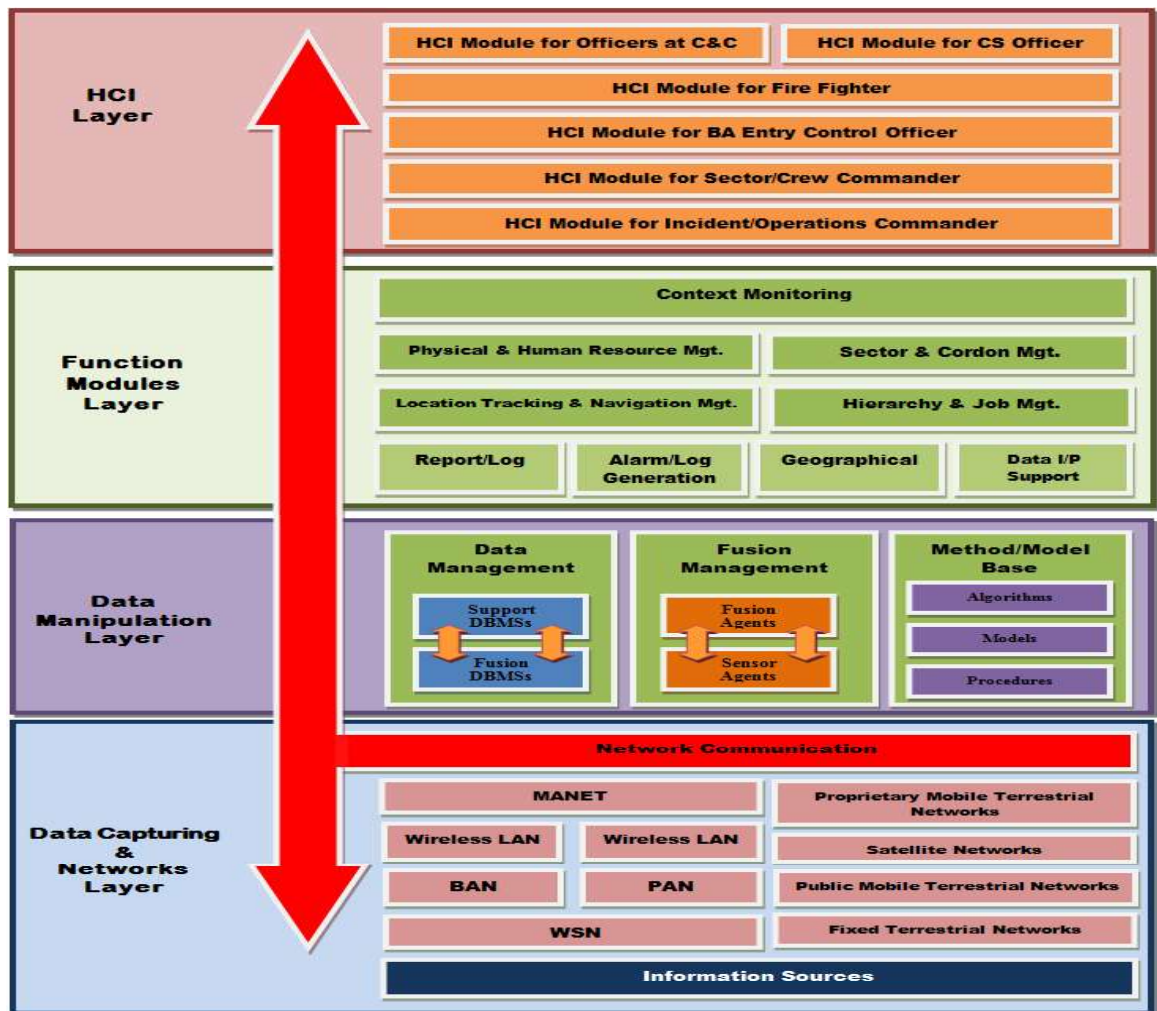


Figure 7.4 : Conceptual ISA for Fire ER Operations

This figure illustrates the components of the architecture presented and explained in the previous sections of this Chapter. It represents the conceptual architecture of fire ER IS for high-risk built environment fires. As explained earlier, it assumes to correspond to the “Owner’s View” of the IS proposed. It is suggested that the above architectural view is well understood by both the owners of the system as well as the systems architects to use as the basis or foundation in identifying and defining the components of their future ER ISs.

Inevitably the ISA proposed consists of few components similar to the components of ISAs such as “WORKPAD” (de Leoni et al., 2007) and “MIKoBOS” (Meissner et al., 2006), which are specified for supporting generic ER. However, the ISA proposed in this chapter is much more comprehensive compared to those architectures that could only address several common needs expected during an emergency and different to those ISAs as it consists of components focus on supporting the needs exclusive to the firefighters. Furthermore, the ISA proposed is unique compared to other ISAs such as “FireGrid” exclusively supporting fire ER, since it is capable of addressing the needs of different types of firefighters rather than addressing generic needs common to fire ER. The ISA proposed constitutes of some specific components that required meeting the identified needs of different firefighters that may enhance their SA during Fire ER.

7.9 Summary

This chapter has proposed a conceptual ISA for fire ER in high-risk built environments. The chapter has explained the components and functionality of each layer of the architecture proposed. The chapter has also considered and explained some challenges and opportunities for existing technologies to implement the architecture proposed. Furthermore, the needs for new research opportunities related to the implementation of this ISA caused by the identified technological opportunities, limitations and challenges are also discussed. The proposed ISA is formulated based on the findings of the first two objectives of this study. Hence, construction of the ISA is driven by previously validated information requirements and the HCI needs of the potential end-users. Importantly, it provides a common discussion platform for end-users, system architects and designers to understand and improve the essential components of an IS supporting fire ER. It will also act as a conceptual benchmark for both clients and designers 1) to compare a system already available or 2) to develop the most appropriate system. This proposed ISA will become the *blueprint*, especially for the system’s architects to design much more comprehensive and technical architectural views suitable for themselves and the system developers in developing an IS for fire and rescue services.

Chapter 8 : Discussion and Conclusions

8.1 Introduction

This chapter aims to discuss the findings and results of this study in the context of the existing literature and makes direct reference to the results from various stages of the research project and the overall research objectives of the study. This chapter begins by explaining the research gap explored in this study. This is then followed by a summary of the study's findings and their contribution to existing knowledge, structured in sections with headings based on the primary objectives considered in Chapter 1. In the following sections, these findings are discussed in terms of their implications for researchers and practitioners. The chapter presents some evidence of the impact of this research for these groups. It finally explains possible limitations and outlines avenues of future inquiry within this area, before concluding with a brief summary of the contribution and the impact of the study presented in this thesis.

8.2 Review of Current Literature and Research Gap

In this section, the literature reviewed in Chapter 2 is recapped, but the relevant references are omitted for convenience and clarity. The literature survey of this study revealed the importance of enhancing the Situation Awareness (SA) of firefighters during their response operations. Previous research carried out in most time-critical complex domains recognized the need of SA for better decision-making. Although there are studies discussing the SA of fire fighters, an extensive literature search did not find any significant literature on the information requirements to improve their SA, and so enhance their decision-making. Most of the studies conducted in the domain of fire emergencies are technology centered. They often focused on introducing particular technology/ies and only addressed and understood a few isolated needs related to SA. Those identified needs are strictly limited to the capabilities of the few selected technologies.

However, there are several noteworthy efforts in the fire ER domain to examine the physical and mental behavioural implications, working patterns, contextual implications of emergency responders. All these efforts acknowledge the significance of understanding human aspects in the systems design process and provide useful in-depth understanding into various fire ER operations. However, their investigations are also confined to the scope

of several specific technologies, thus the outcome of all this work is somewhat limited by the technologies chosen. Very little acknowledgement is made of the differences in the needs created by different responder job roles and their level of experience. More often human centered explorations are focused on understanding one particular need, issue, task or a job. Furthermore, most of the published documentation related to fire emergencies only addresses higher-level generic needs of the firefighters.

In contrast, in similar domains such as military and aviation, developers have managed to improve their systems continuously with the support of the new technology by having a very good understanding on the requirements of their domain operators. In comparison, the lack of understanding of the specific needs of firefighters may have led to slow and low adoption of technology to improve the support systems in the domain of fire emergency. Currently, there are hardly any systems that support firefighters to enhance their SA during their response operations.

Therefore, this study focused on the gaps in the literature related to the lack of knowledge and understanding of 1) firefighter's information needs and 2) how to integrate, share and present the relevant information in a timely and concise manner. By spending more than 1000 contact hours in the form of face to face semi-structured interviews, brainstorming sessions, prototype *walkthrough* and *workshop* sessions with firefighters and members of the related organizations, together with observation of fire and rescue related training and simulation sessions, this study has made an effort to fill the gaps in the literature by achieving the three objectives specified in Chapter 1.

8.3 Contribution of Research Findings

The success in achieving the objectives contributes much needed foundation for future research and development efforts in designing information systems supporting firefighters to enhance SA during their response operations. In the following sub sections, each objective is discussed in terms of the existing knowledge and the contribution of this study to fill the gaps in the literature.

8.3.1 Contribution to Elicitation of Information Requirements

Identification of Important Firefighter Job Roles

The literature related to the UK fire emergency first responder hierarchy, supported by initial discussions and observations made on their operational activities led to the identification of four important types of job roles in the first responder hierarchy: Incident Commanders (ICs), Sector Commanders (SCs), Breathing Apparatus Entry Control Officers (BAECOs) and Breathing Apparatus Wearers or frontline firefighters (Prasanna et al., 2008). Although there were several previous attempts to understand the firefighter requirements most of those efforts focussed either on the overall firefighter hierarchy (FireGrid, 2008; FSEG, 2007a) or one specific job (Jiang et al., 2004a, 2004b; Wilson et al., 2005; Walder et al., 2009). In contrast the findings of this study confirm that identifying the comprehensive needs of these four specific job roles separately is essential since substantial differences between them were found. Furthermore, the findings reveal that the needs of any other job role representing fire incident command hierarchy during a major fire incident could become a subset of the needs of these four core job roles, individually or collectively. Thus, the needs of these four job roles collectively represent the needs of the entire first responder hierarchy. This is in itself an important contribution to understanding the needs of fire fighters.

GDIA: a Tool Capable of Exploring Information Requirements of Firefighters

This study has developed a Cognitive Task Analysis tool to identify the information requirements of fire fighters. The literature indicates challenges to be faced when eliciting the information requirements of end-users in time constrained, complex and difficult environments. Since this particular research focuses on the FRS, a domain where system users experience high-level cognitive complexities and carryout non-rational decision-making during response operations, it chooses to use a suitable Cognitive Task Analysis (CTA) technique. It was argued it is more appropriate to use a CTA tool rather than using a traditional requirements gathering tools found in the conventional information systems design and development literature as such an instrument can capture firefighter requirements comprehensively without losing important requirements.

Various popular CTA tools such as Critical Decision Method (Klein et al., 1989), Critical Incident Technique (Flanagan, 1954), Cognitive Work Analysis (Vicente, 1999) and corresponding techniques used in similar domains were compared in light of the scope of

this study and all were found to have several significant limitations and complexities in applying within the context and scope of this particular research. Among many considered requirements gathering tools, two CTA tools: Applied Cognitive Task Analysis (ACTA) (Militello et al., 1997; Militello and Hutton, 1998) and Goal Directed Cognitive Task Analysis (GDTA) (Endsley et al., 2003b) are identified as more suitable to conduct this particular research (Prasanna et al., 2009; Yang et al., 2009a). However despite significant capabilities, their limitations related to this study lead to the conclusion that the independent use of either GDTA or ACTA is not appropriate and therefore, is not recommended as a means of capturing the information requirements of firefighters (Prasanna et al., 2009). Therefore, a new CTA tool: Goal Direct Information Analysis (GDIA), which specifically supports the elicitation of information needs leading to SA of firefighters, was proposed by synthesizing the strengths of the techniques of two popular CTA tools ACTA and GDTA. GDIA is a scenario based semi-structured interviewing technique, which consists of several clearly defined and specified steps supported by appropriate Meta methods. GDIA overcomes several application and resource constraints and ambiguities in GDTA and ACTA. It is capable of reducing the risk of non-elicitation or misinterpretation of information requirements compared to most of the other CTA tools. With the recommended validation steps, GDIA was expected to reveal comprehensive and accurate information needs in a fewer number of iterations and interviews compared to other similar tools. Furthermore, GDIA is more useful for users who are not specialized in human factors or cognitive psychology and therefore, not familiar with administering other CTA tools or techniques, which are complex and difficult. Therefore, unlike many other CTA tools, GDIA is capable of supporting system designers and analysts who intend to develop systems. It is an ideal tool for a single researcher who is interested in exploring SA requirements in emergency related domains but has limited resources. The results presented in Chapter 4 show that GDIA did fulfil these expectations and made an important contribution to the successful requirement elicitation. Thus, GDIA contributes to eliminates the ambiguity and limitations of other CTA tools such as Applied Cognitive Task Analysis (ACTA) (Militello et al., 1997; Militello and Hutton, 1998) and Goal Directed Cognitive Task Analysis (GDTA) (Endsley et al., 2003b) when apply in conducting research context and scope similar to discuss in this particular research.

Goal Related Information Needs of Firefighters

Using GDIA, information requirements in relation to the goals and decision-making needs of four core firefighter job roles were elicited in three increasing levels of SA, and later validated. These validated information requirements are captured in the form of Goal-Decision-Information (GDI) Diagrams. Altogether, 323 validated GDI diagrams were developed for the four job roles with the breakdown of 88 Diagrams for the IC, 66 diagrams for the SC, 62 diagrams for the BAECO and 107 for the BA Wearer. Rather than just obtaining a list of information requirements, GDIA has led to identifying the link between information needs, decision-making needs and goals of the four different firefighter job roles. It has provided the opportunity to identify specific information needs related to various goals of the firefighters. It also revealed the similarities and differences of information needs across the different firefighter job roles. The feedback obtained from firefighters indicated the success in correctly identifying their information needs. These information requirements add to the knowledge of the outcomes of the previous studies such as Landgren (2007), Deneff et al. (2008), Dyrks et al. (2009) and May et al. (2007). The findings of such previous studies are limited to several common requirements of firefighters in general or focussed on the requirements of one particular firefighter job or requirements related to a specific underline technology. In contrast, this is the first known occasion a study has made a user centred effort to identify the information requirements of different firefighter job roles comprehensively, including the requirements of both novice and experienced personnel. In addition, the information needs identified have laid the foundation to design human computer interfaces capable of enhancing SA of firefighters. Thus, the creation of these 323 GDI diagrams is a major contribution to knowledge about the information needs of fire fighters.

8.3.2 Contribution to Information Presentation and Human Computer Interaction (HCI)

Human Computer Interface Mock-ups of an IS Supporting Firefighters

To achieve this study's second objective, a comprehensive software mock-up addressing the HCI issues and implications of the four key firefighter job roles was developed. This mock-up consists of various human computer interfaces capable of enhancing SA of the selected job roles. Importantly, interfaces proposed in this study are driven by the specific needs of the firefighters identified in the first stage of this study. There have been several significant efforts for specifying human computer interfaces in other similar domains. This

includes interfaces to support emergency medical dispatch teams (Balngford and Wong (2004), Control interfaces for unmanned military vehicles (Connors et al. (2008), Decision support interfaces for army brigades (Riley et al.. 2006) and Dashboards for executives in uncertain financial markets (Resnick, 2003). However, apart from a few commercial products as Vector Command for command support officers (Prendergast, 2007b) and Semi Automated Displays for BAECOs (Drager, 2008) there is very little research conducted in fire emergency domain to comprehensively specify the presentation and sharing of information for different firefighter job roles to enhance SA via appropriate human computer interfaces. Therefore human computer interface mock-ups specified for four firefighter job roles contributes to the knowledge of human computer interaction for emergency response. The mock-up development process also included several demonstration sessions. These were conducted to obtain the feedback of potential end-users. The feedback received confirmed the importance of avoiding human computer design failures that could lead to SA failures in the proposed system. It also revealed some specific design limitations in the interfaces proposed, and provided important suggestions to overcome such shortcomings during the actual systems design. Apart from a few design drawbacks, the feedback confirmed the strengths of many of the design elements and the decisions adopted in the interface design and provided useful comments for further improvements, which were further analyzed in Chapter 6. Rather than just proposing some useful human computer interfaces, this study has extended its contribution by obtaining useful end-user feedback to recommend improvement of their design and development. Thus, the improvements recommended based on the comments of the potential end-users have further strengthened the outcome of the study.

Recommendations for Designing of Human Computer Interfaces of Fire ER Information System

In the process of developing the human computer interfaces, this study has made a series of practical recommendations useful for designing of Human Computer Interfaces supporting fire fighters during ER operations. These recommendations could contribute to the successful development of Fire ER Information Systems and other information systems supporting similar ER situations. These recommendations include several specific interface design decisions specified by *tailoring* various relevant interface design guidelines and principles. This tailoring process is based on the consideration related to the identified information needs of firefighters and some contextual factors unique to the domain of the study. Later,

the usefulness and relevance of these initial design decisions were further improved by proposing refinements and modifications based on the end-user feedback received during mock-up demonstration sessions. In addition, feedback received also led to several other general recommendations that could be very useful for future efforts in developing fire ER information system or any other system supporting similar domains. There exist many general interface guidelines suitable to develop information systems. This includes the significant contributions made in the Human Factors and Ergonomics domains by Boff et al. (1986a; 1986b), Eastman Kodak Company (1983), Sanders and McCormick (1993) and Woodson et al. (1992). SA Oriented Design Guidelines specified by Endsley et al.(2003b) has further strengthened the design of human computer interfaces specifically suitable for enhancing SA of operators working in time critical and complex domains such as Military (Riley et al. ,2006; Connors et al. 2008), Aviation (Endsley et al.,2003b). However, so far there is a very little knowledge related to guide the human computer interface design related to ER domain similar to fire emergency. Thus human computer interface design decisions and other recommendations specified in this research adds to the knowledge of designing human computer interfaces for ER related ISs.

When considering SA related research, generally, there is little previous work in relation to the applicability of SA oriented design to design and development of information systems. Moreover, there is no known literature published in relation to exploring the effects of SA related failures in systems design. Although, Endsley et al. (2003b) have defined some significant SA failures and named them as “SA Demons,” there is no evidence on their relevance and impact in actual design of human computer interfaces. This study has obtained end-users feedback on the relevance and the impact of SA Demons and the appropriateness of the SA oriented design principles related to the design of the proposed human computer interfaces. Therefore, this study is one of the few studies, which have investigated potential end-user feedback in relation to the use of SA oriented design and the impact of SA failures during the design of human computer interfaces of a system.

Innovative Design Concepts for the Development of ER Information Systems

Apart from its overall contribution to SA and the design of ER related systems, this study has presented several innovative design concepts that could significantly contribute to the development of information systems to support fire ER operations or any similar type of

response operations. Among these, the following are considered to make the most significant contribution to the knowledge of the design of ER information systems.

The human computer interfaces proposed in this study are designed so that each one of them is capable of presenting the information in three primary levels of SA: Perception, Comprehension and Projection. The interfaces proposed have allowed each end-user to organise information to enhance all three SA levels depending on their dynamic decision-making requirements related to their goals.

The design concepts of “Mashups” (Taivalsaari and Mikkonen, 2008) suggested the concept of embedding information onto many layers common to various information sources when there are a large number of heterogeneous sources. It was decided to adopt this concept of layered architecture as it is capable of absorbing the demands of the end-users belonging to different firefighter job roles when they seek similar information to support them in achieving the goals that get repeated among many goals of a single job role or goals among different job roles. Furthermore, the concept of developing common layers of architecture is also capable of displaying or presenting specific and individual information demands based on the differences of skills and experience of the individuals. With such flexible capabilities of information display, firefighters are expected to cope with their decision-making better. Apart from enhancing the end-user flexibility, common layers of information enable system developers to reduce their workload. Rather than designing large numbers of different interfaces to address unique end-user needs, this “Mashup” based approach allows designers to design fewer information interfaces. This approach can cope with unique demands of the end-users by providing flexible options of combining several common layers of information to organise their dynamic information needs.

The levels of SA required for any type of a firefighter job varies rapidly due to highly dynamic contextual conditions during a fire emergency. Therefore, the cognitive demands for SA of a firefighter change from perception level SA to comprehension level SA and from comprehension to projection level SA within a very short period. Having considered these SA related requirements, firefighters are provided with the facility of dynamic interchangeable access between different interfaces containing appropriate information capable of enhancing the required levels of SA.

Feedback received during the mock-up demonstrations has confirmed that it is very important to design interfaces in such a way that they are capable of displaying information related to the end-users goals. However, there is very little guidance available for the interface designers on how to achieve it in practice. This study has managed to propose a novel way to organise the end-user information, which was strongly supported by the end-user feedback. As explained in Chapter 6, having considered the participant feedback related to the information display, this study proposes an interface design concept and a concept that enhances individual end-user customization. With these concepts, end-users with different work experiences and skills will be able to access interfaces displaying information uniquely customized for their preferences when they are attending a particular goal. It is suggested that these design concepts proposed in this study will augment the SA oriented design principles and encourage the system designers to apply them in other similar type of interface design.

The concept of “Black Box,” a device popular in the aviation, is a novel concept of an interface proposed for the firefighters to enhance their SA to carry out briefing, debriefing sessions and post incident considerations. These activities are crucial, not only for the success of on-site response operations, but also for the off-site activities such as forensic and criminal investigations, business continuity assessments and training activities that could be carried out sometime after the actual operation. At present, firefighters are struggling to maintain necessary SA to successfully carry out these activities. The feedback received clearly supports the capability of the interface “Black Box,” not only as a concept that could enhance the SA of firefighters, but as a concept that could be useful to overcome many SA Demons. Therefore, this particular conceptual interface is recommended for use in other emergency related domains where end-users struggle to find and preserve information that is primarily useful for their 1) post incident considerations, 2) briefing and 3) debriefing activities.

To overcome various SA related difficulties and challenges for BA Wearers, this study has proposed the implementation of two new human computer interfaces: “Guideline” and “Route Planner.” In the feedback sessions, most of the potential end-users considered “Guideline” and “Route Planner” were perfect solutions to substitute for the unpopular traditional practice of using physical guidelines for firefighter navigation. There has been some significant work related to navigation and location tracking of frontline firefighters on

the move and recently Ramirez et al. (2009) proposed novel design concepts aimed at supporting firefighters in creating and finding their own paths. The proposed design concept in this study adds to the body of the knowledge of this previous research. Compared to previous studies, the concept proposed is somewhat different as it is the first time the conceptual human computer interfaces have been specified for both the firefighter and their entry control officer.

Bearing in mind the end-user behavioural requirements such as continuous mobility, higher levels of hands free and eyes free requirements, the decision on the mode of information delivery for frontline firefighters is difficult. However, considering the pros and cons of currently used firefighter display devices such as thermal image camera and considering extensive use of voice communication by the firefighters during their operations, this study recommends a multimodal interface, which embeds both audio and visual for BA Wearers. Although previous research (Wilson et al., 2005; Wilson and Wright, 2007; Bretschneider et al., 2006) has proposed visual head mounted displays for the use of moving firefighters, they are primarily focused on the display of information and various human factor issues related to visual capability. However, the concept proposed in this study has extended the previous research as it not only considered the display of information, but also considered the controllability implications related to the display devices. Having considered the end-user reluctance and the difficulty to use both hands to control the device and other contextual challenges, this study proposes to control the visual interface via simple voice commands. However, the fire incident ground is very noisy. Therefore, to control a device with natural voice is impossible. So the use of throat operated microphones was proposed to replace the natural voice for controlling the BA Wearer visual interface. The concept of having a multimodal display, which can be controlled by the voice of firefighters captured via a throat operated microphone, was praised by most of the end-users. This is the first known occasion a concept of head mounted visual display for firefighters controlled by a throat operated microphone has been proposed and evaluated.

The outcome of this study is different from similar research carried out so far. At present in the UK, there is very little literature published related to the human computer interfaces capable of delivering SA needs of key firefighter job roles. The only available literature is limited to a few commercially available products such as Vector Command (Prendergast, 2007a; 2007b; 2009). These products do not address most of the information needs and

issues related to the presentation of information. Similarly, most of the previous academic research efforts carried out in the UK (Berry et al., 2005; FSEG, 2007a, 2007b; May et al., 2007) other parts of the world (Bergstrand and Landgren,2009; Walder et al., 2009; Landgren , 2007; RUNES, 2006; Jiang et al. ,2004a,2004b) related to fire emergency information systems are also focused on the use of a particular technology/ies and address only a few selected needs limited by the scope of the technology promoted by the study. In contrast, this study has managed to explore and explain how to present the information to enhance SA for various specific firefighter job roles comprehensively via suitable human computer interfaces. This is the first known occasion where an early software prototype of an information system capable of looking after SA needs of firefighters is developed and evaluated. Thus, the knowledge gained in this study fills an important gap in existing knowledge.

8.3.3 Contribution to Information Systems Architecture

Conceptual Information Systems Architecture for Fire ER

This study proposed a high-level conceptual architecture of the system that is capable of deploying the human computer interfaces suitable of supporting various firefighter job roles during fire ER. The Information Systems Architecture (ISA) proposed defines the essential components that should be embedded into the system. There is very little literature clearly explaining the high-level systems architecture of systems supporting fire ER, which is well understood by both the owners of the system as well as the systems architects. Majority of the previous work that proposed ISA are focused on either a generic ER (Meissner et al., 2006; Madey et al.,2006; de Leoni et al., 2007) operations or specific ER operations different to fire ER (Kwan and Lee, 2005; Hwang et al., 2007; Lorincz et al., 2004). Even the very few previously proposed fire ER related ISAs such as “Friegrid” (Upadhyay et al., 2008) are less comprehensive and focus on a few selected needs of the end-users or a few technologies. In contrast, the construction of the proposed ISA is driven by the previously validated information requirements and the HCI needs of the potential end-users. Therefore, the ISA proposed is more relevant and comprehensive compared to most of the previous suggestions.

This ISA provides a common discussion platform that could be beneficial for both end-users and system designers to understand, design, develop or modify the components of an IS supporting fire ER. It could be an ideal benchmark for both clients and designers to

compare a system already available or to develop the most appropriate system from scratch. Furthermore, the proposed ISA could become the *blue print*, especially for the system architects to design architectural views, which are more technical and suitable for the system developers in developing an information system for FRs.

Challenges and Opportunities for the Development of Information System Supporting Fire ER

This study also identified challenges and opportunities in relation to practical implementation of the proposed ISA supporting fire ER; including feasibility of various emerging technologies and ongoing research that could be adopted to form the essential components of the ISA. It was identified that currently available technologies have some major limitations, making practical implementation of all the HCI components required for supporting some of the firefighters very difficult. The technological limitations are most eminent for the job roles of BAECOs and BA Wearers, thus full implementation of all the HCI components required for these two job roles are highly unlikely without some extensive further research. To overcome the barriers and limitations related to the current technology, in Chapter 7 this study has proposed several recommendations for future research, which could extend the services of information capturing devices, networks and networking technologies and information display devices. These opportunities and challenges identified should contribute to a better discussion in various related research domains so that in the future, emerging technologies could be better adopted for the benefit of fire ER operations.

8.4 Impact of the Study

So far, the results of this study have been published in four peer reviewed conferences and three journals. There are indications already from both the research and practitioner communities to suggest this study will have a significant impact.

A research group in New Zealand involved in designing a Decision Support System (DSS) to improve SA for overall improvement in Decision-making during emergency situations arising from a volcanic eruption (Javed et al., 2009, NZPA, 2010) has decided to use GDIA as their primary tool for requirements elicitation.

Similarly, one of the research groups in SINTEF in Norway (SINTEF, 2010), which is exclusively looking at the design and development of IS for fire emergency responders have requested permission to use the findings described in the GDI diagrams created in Chapter 4 of this thesis. According to one of their representatives in the Cooperative and Trusted Systems research group of this organization; they are inspired by the work published by this study in relation to the information needs of firefighters. These researchers are looking forward to building on the outcomes of this study and use it as the basis to develop a system supporting different firefighter job roles.

Recent reforms and changes in the UK FRS have led to significant interest in acquiring suitable information systems support during their response operations. Thus, many of the FRS brigades representing various counties are currently running feasibility studies and pilot programs either to purchase off the shelf products from a commercial vendor, such as Vector Command, or to develop a system on their own with the use of Geographical Information System (GIS) software. However, there is minimal guidance and support available in acquiring such support systems since there is a knowledge gap in designing the best suited human computer interfaces. Therefore, in relation to the current context of the UK FRS, the software mock-ups consisting of human computer interfaces proposed in this study and the specific interface design decisions adopted in developing them, design modifications, improvements and other useful findings based on the end-users feedback are very timely. These outcomes provide much needed guidance and a solid foundation for the information system designers and developers to design better human computer interfaces for firefighters to enhance their SA during ER operations.

As mentioned in Chapter 2, one of the major IS/IT acquiring project in the UK FRS: FiReControl will be delayed for another four years and will not be completed until 2012. According to the National Audit Office Report for the Fire Control Project (NAO, 2010), one of the primary causes for this delay is the inability of the system providers to clearly identify in-depth requirements of individual end-users since its start in 2004. EADS, a large system integrating company is charged with delivering the FiReControl project (EADS Defence & Security, 2010). According to the recent House of Commons Select Committee's Report on the Department for Communities and Local Government's FiReControl Project (2010), there appeared to be no "real world" knowhow of the end-user needs. In the same report, CEO of the EADS also accepted their failures and inability in

recognizing the needs of the actual end-users. The stakeholders of the FiReControl project have now identified the findings and results of this study as one of the useful means of understanding more on the actual needs of the firefighters to expedite the progress of their delayed project. The Office of the Chief Fire and Rescue Adviser, which coordinates and monitors the progress of the FiReControl project has officially invited the author to present the findings of this study to its members as well the officials of EADS. This indicate that professionals and practitioners involved in the IS/IT developments in the UK FRS have recognized the significant contribution made by this study.

Practical use of the findings of this study includes Leicestershire FRS, where it has decided to use the information needs identified for the job role of IC as the primary input in one of their pilot projects for developing command support system. The team members involved in this pilot project believe that the information needs identified in this study in relation to the decisions and goals of an IC are comprehensive enough to address the needs during any large-scale building fires in their county. They also believe that by just maintaining the goal driven information needs (GDI diagrams) in a database with quick access via a goal based menu will enhance the command support to ICs tremendously.

8.5 Limitations and Avenues for Future Research

First, a significant limitation of this study is that a relatively small number of scenarios were selected to represent a fire in high-risk built environments. It was envisaged that by adding more scenarios it would be possible to improve the comprehensiveness of the needs of firefighters in attending high-risk built environments. However, it is acknowledged that the selected scenarios for this study may not have provided representative views for all type of fire emergencies expected in high-risk built environments. It is suggested that future research needs to gauge the views of more fire scenarios to build up a more robust understanding of the complex situations expected in large-scale built environment fires.

Second, investigations of this study are limited to the high-risk built environments located within the East Midlands region of the UK. However, most of the highest risks buildings of the country are located in an around the London Metropolitan area. Therefore, incidents sites selected for this study may not accurately represent the profile of the highest risks buildings in the UK. Therefore, it is recommended to conduct future research with the

participation of FRS brigades, which are responsible for the highest risk built environment of the country.

The third limitation of the study is its approach to mock-up evaluation sessions. Throughout, all the evaluation sessions of this study were conducted in the office environment. During the prototype walkthrough sessions, participants observed the functionality and application of the proposed system use for a hypothetical fire scenario/s with the use of a large screen fixed inside a room. During the workshop session, participants used a personal computer to interact with the mock-ups by themselves to check its usefulness and applicability to different fire scenarios. However, this evaluation environment is contextually different from the conditions expected during an actual fire. These contextual differences may have some significant impact on the participant feedback during the mock-up evaluation sessions. Therefore, it is strongly recommended to extend the mock-up evaluation by conducting further evaluation sessions; especially the walkthrough sessions, in a more appropriate experimental setting, which can better simulate and control the conditions and the environment of the fire scenarios used for the evaluation.

The fourth limitation of the study is that the design of human computer interfaces is limited to low fidelity software mock-ups which demonstrate less functionality during its use. Predominantly static nature of the proposed interfaces could have prevented the end-users from expressing some of the usability issues related to the IS. Also their limited capability of simulating the features of an actual IS could have avoided some end-user requirements. Therefore it is recommend to develop a prototype of the IS which is capable of closely simulate the functionality of actual system so that it allows to solicit the final end-user requirements.

Another limitation of this study is the relatively small number of informants interviewed. Although many interviews were conducted in several stages, the maximum number of interviews conducted in a particular stage for a one particular job role was limited to five informants. These informant's samples were selected in such a way that it essentially consisted of SMEs having different levels of experience. However, having recognized the importance of comprehensively identifying the needs of firefighters that represent the whole continuum from the least experienced to the highest experienced, the number of interviews conducted may not be adequate to build up a balanced and holistic

understanding of the needs of both novice and the experienced firefighters. This becomes more significant since it emerged during the study that needs of the firefighters not only differs due to the level of their experience but it could also vary due to the type of employment, full-time firefighter or as a retained firefighter. Future research needs to gauge the views of more staff in each stage of the information gathering to improve the design and development of the Information System so that it can assure its support for firefighters with different backgrounds and performance levels.

This study also identified several limitations and issues related to the design and development of the type of information system proposed. The detail explanations of those were made in Chapter 6 and Chapter 7 with recommendations for improvement and further research.

It is clearly evident that having taken a case study based interpretive approach to conduct the explorations; there is a fair degree of subjectivity involved in the opinions of the subject-matter experts who participated in the application of GDIA as well as during the two mock-up evaluations. Similarly, throughout all stages of the study, it was impossible to avoid the subjectivity of the author in the capturing, analysis and interpretation of the participant's opinions, since the author of this study adopted the philosophy of an interpretivist. Nonetheless, compared to any other previous research, the author of this study believes that tools and techniques used have provided a sound approach to delineating the SA requirements of the firefighters during their response operations. However in order to minimise the unwanted subjectivity of the findings and to further fine-tune and improve the generalisation of the findings to a much wider community of firefighters, it is strongly suggested to further expand the requirements capturing studies using a technique like Delphi (Linstone and Murray, 2002) with the participation of much larger number of firefighters belonging to fire brigades across many countries or regions.

During the design of the human computer interfaces and ISA for fire ER this study has identified new design concepts such as: Computer based Virtual Guideline for BA Wearer Navigation and Location Tracking, Large Display Devices for BAECOs, HMD Displays controlled by voice commands and Visual Black Box supporting firefighters for post incident, briefing and debriefing. It is clearly evident that successful implementation of these new information system concepts entirely depend on the support of several new

generation software and hardware technologies such as agent based wireless sensor networks, throat operated microphones, voice recognition, and virtual reality based displays. Therefore there is an essential need for future research and feasibility studies focussed on such new generation technologies. Importantly the future research efforts to enhance the technological support for fire ER could be immensely supported by referring to the literature and research related to the latest state of art technology adaptations in the similar domains such as military, aviation and medical. The “Future Soldier” is one such prominent research which could immensely help inform the research in Fire ER. The “Future Solder” is a multi-nation military project by the United States and other NATO countries focused on enhancing the psychological and tactical preparation of ground combat soldier with use of latest technological advancements in the fields of electro-mechanical and communication.

8.5 Concluding Remarks

The outcomes of this study include an enhanced cognitive task analysis tool capable of exploring the needs of firefighters, a large set of “GDI Diagrams” showing a hierarchy of goal related information needs for each of the job roles with the link to their decision-making needs, several human computer interface mock-ups for an information system to enhance Situation Awareness of firefighters, a series of practical recommendations for presenting this information and specific interface design decisions suitable in developing fire emergency response information systems. The outcomes of this study also include a conceptual architecture proposed for the underlying information system supporting fire ER. Thus, this study has managed to identify the comprehensive needs of the fire emergency responders to enhance their SA so that they can make better decisions with the support of an information system. In conclusion, this study has provided valuable input to both theory and methodological practice for the design and development of information systems for fire ER. Essentially this particular study is focussed on fire emergencies strictly related to large buildings having high fire risk. However, it is clearly evident that most of the findings related to information requirements and requirements related human computer interaction could be extended to support other unique fire related emergencies such as large forest fires, high way or motor way related fires. Similarly, findings of this study could be further extended to supporting other ER activities such as Volcanic Eruptions, Earthquakes, and Floods.

This study has emphasized that academics and practitioners need to consider and understand the requirements of the actual end-users; in this particular case firefighters, to achieve system success. The findings of this study has also revealed that the long term evolution of a information system supporting firefighters during their response operations essentially requires the consideration of integrating the emergency planning, firefighter training and emergency response issues. Failure to do this is likely to prolong the current poor performance of many IS development projects in the domain of ER; specifically related to the fire ER.

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Appendices

Appendix 3.1: Software Prototyping Tools

| Popular conventional Rapid Software Coding tools | Presentation tools | Tools Exclusively to generate Graphical User Interfaces |
|---------------------------------------------------------|---------------------------|----------------------------------------------------------------|
| Visual Basic | Microsoft Power Point | OmniGraffle Pro |
| Borland Delphi | Adobe Director | Axure RP Pro |
| Microsoft Access | Adobe Flash | iRise Pro |
| | Visio | Pencil |
| | | GUI Design Studio |
| | | Emultek Rapid |
| | | Virtual Prototypes VAPS |
| | | Tool Book |
| | | Small Talk |
| | | SmartDraw |
| | | Mockup Screens |
| | | Balsamiq Mockups |
| | | Lucid Spec |
| | | ConceptDraw Pro |
| | | iPlotz |

Appendix 4.1: Sample of Catalogued Field Notes related to the Job Role of IC (Observations made at the Westfield Centre Live Fire Simulation Exercise)

Scenario: 999 fire call from Westfield Centre Control Room on 10th December 2007 at 8.00pm received at Derbyshire Fire and Rescue Command and Control. Multiple fires detected by the control room CCTV at the roof top car park and in the top floor clothing shop compartment.

Observations started outside the incident premise and observer accompanied one of the senior fire officers who received a *role call* from the Control Room requesting him to attend the incident immediately and asking him to take over the role of an Incident Commander.

Field Note Ref. 1.1:

When received the *role call* IC showed a need and concerned to access specific operational risk reviews (Category 3 or 4).

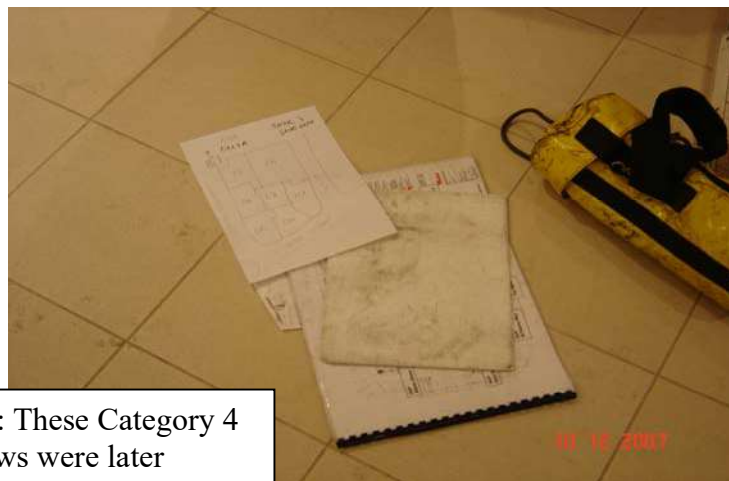


Photo 1.1: These Category 4 risk reviews were later

Field Note Ref. 1.2:

On the way to the incident IC requested Control room to connect him to the current Officer In charge (OIC) at the incident.

Field Note Ref. 1.3:

IC reconfirmed the location of the rendezvous point by talking to Control Room and later to the incident O.I.C.

Field Note Ref. 1.4:

New IC circled around the incident, self observing current condition of the incident before assuming duty as the IC.

Field Note Ref. 1.5:

Senior officers took their time before committing themselves as the IC. They were talking to the current OIC asking whether things are under control. Further, asked about the deployed tactics and control measures.

Field Note Ref. 1.6:

Senior officer who intend to become the next IC asked the current OIC about the possibility of casualty inside the building. It seemed to be the main concern of the senior officer before committing, as he was desperate to get some confirmed information about the possible casualties in the danger area.

Field Note Ref. 1.7:

As the incident progressed and became complex, several IC takeovers were observed with substitution of experienced officers to replace junior officers.



Photo 1.7: At the beginning this Sector Commander was acting as the first IC

Field Note Ref. 1.8:

Change of tactical mode from *delta offensive* to *delta defensive* is informed by the IC to the sector commanders via a hand held two-way radio.

Field Note Ref. 1.9:

IC wants to know the way hazards are spreading in the fire sector and what is the expected escalation of hazards including fire. This was done by talking to the fire sector commander using the two way radio.

Field Note Ref. 1.10:

IC asked command support to order a high volume water pump. A white board located at the command support post indicated that this request was originally made by the fire sector commander. IC authorized that by requesting command support to forward the request to the control room.

Field Note Ref. 1.11:

Fire sector commander received a call from IC requesting details about how he is fairing with regard to his resources. Sector commander explained that he can currently manage with the existing hose reels but may need BA cylinders to be refilled soon.

Field Note Ref. 1.12:

Time to time IC observed at the white board, which carries the tactical and operational activities.

Field Note Ref. 1.13:

IC is concerned about the runoff water. He requested a confirmation from the fire sector commander whether appropriate drains are identified to put the runoff water. Just after that call he asked one of the command support team members to check the available drains to put the runoff water.

Field Note Ref. 1.14:

IC discussed with others to release unwanted resources. By that time, several fire engines had already left the incident. After fire in the roof top was extinguished, IC released some unwanted resources.



Photo 1.14: One of the fire engines preparing to leave just after extinguishing the roof top

Field Note Ref. 1.15:

Just after finishing the operational activities, a post incident debrief was conducted by the IC. For this activity incident command team comprised of sector commanders, command support team members along with IC participated. Main theme of the discussion was how they managed the operation during the incident. Some important observations made by sectors commanders with regard to overall safety of fire fighters were also discussed. **(Voice Clip 1.15)**

Appendix 4.2: Fire Scenarios Used as the GDIA Interviewing Probes

1st Scenario

- Fire in one of the clothing shops located on the 2nd Floor of the Westfield Centre Derbyshire.

Date: Week Day Time: 3.00 in the afternoon.

Details: a 999 call is received at the Derby Fire and Rescue Control Room from the Westfield Command & Control, specifying details of above fire. Currently, no casualties reported. Situation should be decided based on the above reported information.

Variations:

Depending on the Job Role

You are deployed as a member of the first fire engine/ subsequent fire engines that reaches the incident and act as a BA Wearer or BA ECO.

You are deployed as a SC at a later stage of the incident.

You are deployed as the first OIC to reach the incident (First IC)

As a senior officer, you are deployed as an IC after the arrival of first fleet of vehicles at the incident. At this moment of time, there is already an OIC of lower rank working at the incident. He has already implemented some strategies (Subsequent IC in a protracted fire).

Time of the Incident

Vary the time of the incident to 1) Midnight, 2) Morning rush hour. Date can be varied to a 1) Weekday, 2) Weekend and 3) public holiday as required.

Location of the Reported Fire

Location of the fire can be shifted from the 2nd floor Clothing Shop to a kitchen in one of the Restaurants located on the 1st floor, Basement, Roof top car park or one of the proposed cinema theatres.

2nd Scenario

- Fire in one of the flats located on the 4th floor of Bath Street Flats Community Housing in Derbyshire.

Date: Weekday, Time: Midnight.

Details: 999 call is received at the Derby Fire and Rescue Control Room from the Bath Street Community Housing Security specifying, details of the above fire. Currently, several casualties are report in one of the 4th floor flats. Fire seems to be spreading to other flats in the same floor. Situation should be decided based on the above reported information.

Variations:

Depending on the Job Role

You are deployed as a member of the first fire engine/ subsequent fire engines that reaches the incident and act as a BA Wearer or BA ECO.

You are deployed as a SC at a later stage of the incident.

You are deployed as the first OIC to reach the incident (First IC).

As a senior officer, you are deployed as an IC after the arrival of first fleet of vehicles at the incident. At this moment of time, there is already an OIC of lower rank working at the incident. He has already implemented some strategies (Subsequent IC in a protracted fire).

Time of the Incident

Vary the time of the incident to 1) Midnight, 2) Morning rush hour. Date can be varied to a 1) Weekday, 2) Weekend and 3) public holiday as required.

Location of the Reported Fire

Location of the fire can be shifted from 4th Floor to the Basement Car Park or the Roof top.

3rd Scenario

Fire in one of the Nurses Quarters on the 5th floor of Derbyshire Infirmary Nurses Quarters.

Date: Sunday, Time: 5 in the evening.

Details: 999 call is received at the Derby Fire and Rescue Control Room from the Warden of the Royal Infirmary Nurses Quarters specifying details of the above fire. Currently few casualties are report in a dormitory located on the 6th floor. Fire seems to be contained to a single dormitory on the 5th Floor. Situation should be decided based on the above reported information.

Variations:

Depending on the Job Role

You are deployed as a member of the first fire engine/ subsequent fire engines that reaches the incident and act as a BA Wearer or BA ECO.

You are deployed as a SC at a later stage of the incident.

You are deployed as the first OIC to reach the incident (First IC).

As a senior officer, you are deployed as an IC after the arrival of first fleet of vehicles at the incident. At this moment of time, there is already an OIC of lower rank working at the incident. He has already implemented some strategies (Subsequent IC in a protracted fire).

Time of the Incident

Vary the time of the incident to 1) Midnight, 2) Morning rush hour. Date can be varied to a 1) Weekday, 2) Weekend and 3) public holiday as required.

Location of the Reported Fire

Location of fire can be shifted from the 5th Floor to the Basement Car Park or spread to other floors adjacent to the 5th floor.

4th Scenario

- Fire in Rolls Royce Nuclear, Derbyshire.
Date: Weekday 10 in the Morning.

Details: 999 call is received at the Derby Fire and Rescue Control Room from the Fire Fighting Unit at Rolls Royce, asking support with the details of the above fire. Currently there are no casualties reported. Laboratory may consist with harmful chemicals and radioactive materials. The fire seems to be spreading from its origin to other parts of the building. Situation should be decided based on the above reported information.

Variations:

Depending on the Job Role

You are deployed as a member of the first fire engine/ subsequent fire engines that reaches the incident and act as a BA Wearer or BA ECO.

You are deployed as a SC at a later stage of the incident.

You are deployed as the first OIC to reach the incident (First IC).

As a senior officer, you are deployed as an IC after the arrival of first fleet of vehicles at the incident. At this moment of time, there is already an OIC of lower rank working at the incident. He has already implemented some strategies (Subsequent IC in a protracted fire).

Time of the Incident

Vary the time of the incident to 1) Midnight, 2) Morning rush hour. Date can be varied to a 1) Weekday, 2) Weekend and 3) public holiday as required.

Location of the Reported Fire

Location of the fire can be shifted from the Laboratory to the equipment testing areas or manufacturing bays.

Appendix 4.3: List of SMEs selected for the Task Elicitation Interviews

| Reference | Job Role | Fire Station | Designation | Experience |
|---------------|--------------------|--------------|--------------------|----------------------------------------------------|
| Interviewee 1 | Incident Commander | Ascot Drive | Area Group Manager | 15 Years as an IC Bronze and Silver level IC |
| Interviewee 2 | Sector Commander | Notts. Road | Station Manager | 20 Year Experience as a Sector Commander |
| Interviewee 3 | Incident Commander | Swadlincote | Station Manager | 3 Years experience as a Incident Commander |
| Interviewee 4 | Sector Commander | Ascot Drive | Senior Firefighter | 2 Year Experience as a Sector Commander |
| Interviewee 5 | BA Entry Control | Ascot Drive | Senior Firefighter | 13 Years Experience as a BA ECO |
| Interviewee 6 | BA Wearer | Ascot Drive | Senior FireFighter | 15 Years Experience as a Firefighter |
| Interviewee 7 | BA entry Control | Notts Road | Firefighter | 2.5 Years Experience as a BAECO |
| Interviewee 8 | BA Wearer | Ripley | Firefighter | 3 years experience as a Firefighter |

Appendix 4.4: Interview Guide for Task Elicitation

Approximate Duration: Maximum 2 Hrs. On average 1.5Hrs.

Type of Interview: Semi-structured - guided with pre identified scenario probes.

1. Scenarios to be used:
 - Fire in one of the clothing shops located on the 2nd Floor of the Westfield Centre Derbyshire. Date: Week Day Time: 3.00 in the afternoon.
 - Fire in one of the flats on the 4th floor of the Bath Street flats Community housing in Derbyshire.
Date: Weekday, Time: Midnight.
 - Fire in one of the Nurses Quarters on the 5th floor of Derbyshire Infirmary Nurses Quarters.
Date: Sunday, Time: 5 in the evening.
 - Fire in Rolls Royce Nuclear Labs in Derbyshire.
Date: Weekday 10 in the Morning.

Discuss four scenarios; explaining the situation in each scenario by a step by step verbal walkthrough with the participant. Request any further clarification to be made. If there are any gray areas or misinterpretations, discuss and clarify such issues so that interviewee would finally have a clear mental picture of the situations being elaborated in the scenarios.

2. Explain what you are looking forward to capture during this interview. In this particular phase of the interviews in relation to the emergency response scope described in the four scenarios, it is primarily to capture the operational tasks expected to achieve by the interviewee driven by their job role responsibilities.

3. Thereafter, ask the interviewee to describe and list possible tasks he/she may have to carry out to overcome the situations described in the scenarios.

A specific grand tour question could be formulated as below.

Question:

During the above mentioned scenario, situations what sort of jobs or tasks you may have to carry out in order to make it a successful operation.

4. This can be achieved with the use of additional interview prompts which motivate interviewees to look into the situation from a different viewpoint or motivate him to describe the tasks with clear elaborations.

Such prompts could be:

Can you explain this particular situation further...?

Can you elaborate further on this?

Could you give me an example?

Could you elaborate your own experience?

Could you explain any similar situation?

The above type of floating prompts in combination with the variations introduced to the original scenarios would expand their imagination boundaries and therefore, lead to a comprehensive answer. Such variations could be to in the form of introduction of different time periods, different floor levels, different types of hazards compared to the original scenario. It is considered as important to introduce variations to the scenarios whenever interviewees find it difficult to express tasks explicitly or show signs of boredom.

5. Make sure to obtain a comprehensive list of operational task related to each job role at the end of the interview.

Depending on the availability of time

6. Introduce changes to the incident location of the basic scenarios and request interviewees to elaborate on extensions or changes to their expectations and motives.

Example: By asking the question:

What would be the situation if similar type of fire occurred in the first floor of Chatsworth House (Famous Heritage Site in Derby)? Would there be any additional tasks that you may have to perform during the operations?

If interviewees ignore or give a simple answer to the above type of variations, putting forward a situation mentioned in a previous scenario and by asking the interviewee to identify any task variation from the previous scenario to this new situation could be helpful to elicit much elaborative descriptions.

Example: Comparing new scenario with previous scenario related to Westfield Centre, in relation to the above question:

What sort of additional tasks do you have to perform during this new situation compared to the situation mentioned in the Westfield Scenario?

Or

Would there be any difference to the tasks compared to the Westfield Scenario?

As elaborated above, introduction of scenario variations and floating alterations during the actual interviews are expected to capture useful tasks, which may have not been identified with the first set of scenarios.

7. Efforts should be made to identify any priority in identified tasks.
8. Efforts should be made to identify any compulsory or prime tasks.
9. Efforts should be made to identify any competing tasks.
10. Relevant to each scenario, investigate whether there are tasks that are difficult or cumbersome to carry out with currently available resources or technology.
11. If answer is “Yes” for the above question, inquire why interviewees don’t like those particular tasks. Check whether they have any alternative suggestions to do them better.

At the end of each interview, it is important to mention the expected outcome of the interviews, and also explain why the findings of this interview are essential to carry out the next round of interviews to elicit the goals. Finally, requests continuous support of the interviewees for the future interview phases. Session should be closed by thanking the interviewer for the participation.

Appendix 4.5: Interpretation of Tasks for the Job Role Incident Commander

| Initial Stage - 999 Call till Arrival | Interpretation of Task |
|------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| | Get to know the role of mobilization |
| | Acknowledge receipt of roll call an mobilization |
| | Contact control for the initial information of the incident situation |
| | Request more information directly from the incident via control |
| | Check the availability of operational plan |
| | Quick look at the incident related maps (geographic and building) |
| | Verify the location of the rendezvous point |
| | Look around the environment for more information |
| | Listen to the radio |
| | Get the list of resources deployed at the moment |
| | Go through Profiles of the deployed officers |
| | Request any updates of incidents from the control |
| | Get advice on traffic conditions |
| | Get the address of the incident |
| Arrival till take over | Report to the rendezvous point |
| | Vehicle parking |
| | Put the fire kit |
| | Wonder around and observe |
| | Find out who is in charge of the situation |
| | Let officer in charge know the arrival |
| | Talk to the officer in charge and get a brief |
| | Talk to responsible officers representing the client. <ul style="list-style-type: none"> ▪ from the control room ▪ Talk to marshalling officers of buildings if available |
| | Talking to chemical specialists at the incident |
| | Go through available CCTV footage of the building |
| | Take over incident command position |
| | Inform control after taking over |
| | Try to access the fire alarm panel of the building |
| | Get a confirmation of any casualties |
| | Monitor available resources |
| | get a visual picture of the incident |
| | Get hold of the operational plans, building plans, operation safety plans |
| | May talk to the people evacuating |
| | Go through the operational plan, operational notes, building plans |
| | Got to know the traffic conditions in the surrounding |
| Take over till take a step back | Initial Dynamic risk assessment |
| | Formulating or amending incident plan |
| | Access Hazmat Data <ul style="list-style-type: none"> ▪ Resource assessment ▪ Identify new requirements ▪ Request new requirements via command support |
| | Build Basic IC Structure (Not Comprehensive Structure with complete sectorisation) |
| | Task allocation |
| | Communicate the tactical mode |

| | |
|--------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------|
| | Start Passing the decisions back to control |
| | Compare your own picture with the picture getting from the officer in charge |
| | Monitor the status of ordered resources. Request any additional resources and monitor their arrival |
| | Discuss/Advice other commanders to carry out the plans |
| | <ul style="list-style-type: none"> • Setup bridge head • Setup Lobby sector |
| | Setup Safety zones (cordons) |
| | Initiation and monitoring <ul style="list-style-type: none"> ▪ Fire fighting ▪ Salvage ▪ ventilation |
| | Set up BA teams |
| After settle down | Operational and Functional Sectorisation and expansion of IC structure |
| | Direct and coordinate resources |
| | Brief and keep subordinate informed throughout the incident |
| | Carry out analytical risk assessment |
| | Acquire weather data |
| | Talk to building inspectors from the local authority |
| | Talk to safety officers |
| | Liaise with media, police ,ambulance |
| | Ask commanders to report back |
| | Make a communication plan |
| | Listen to different commanders frequently |
| | Monitor and maintain staff welfare |
| | Check any additional logistical needs |
| | Monitor tactical operations. |
| | Compare actual progress to planned tactics. |
| | Re-evaluate and adjust assignments based on changing conditions or situations. |
| | Maintain records on a white board |
| | Re-evaluate the risk management process and ensure appropriate situation awareness. |
| | Advice subordinates of changes. |
| Ask fire fighters to contain any available Hazmat | |
| Ask fire fighters to either extinguish or contain fire | |
| Ask fire fighters to carry out Ventilation | |
| Finishing Stage | Identify officer to gather information for post incident review |
| | Maintaining Control over the safe systems of work |
| | Debrief with sector and functional commanders and command support |
| | Release any unwanted resources |

Appendix 4.6: List of SME's selected for the Goal Elicitation Interviews

| Reference | Job Role | Fire Station | Designation | Experience |
|----------------|--------------------|--------------|--------------------|------------------------------------------------------|
| Interviewee 1 | Incident Commander | Ascot Drive | Area Group Manager | 15 Years as an IC Bronze and Silver level IC |
| Interviewee 2 | Incident Commander | Reply | Station Manager | 18Year as an IC Bronze (Retained) |
| Interviewee 3 | Incident Commander | Swadlincote | Station Manager | 3 Years experience as a Incident Commander |
| Interviewee 4 | Incident Commander | Old Hall | Station Manager | 4 Years experience as a Incident Commander |
| Interviewee 5 | Sector Commander | Notts. Road | Station Manager | 20 Year Experience as a Sector Commander |
| Interviewee 6 | Sector Commander | Swadlincote | Watch Manager | 15 Years Experience as a Sector Commander (Retained) |
| Interviewee 7 | Sector Commander | Ascot Drive | Watch Manager | 5 Years Experience as a Sector Commander |
| Interviewee 8 | Sector Commander | Long Eaton | Senior Firefighter | 2 Year Experience as a Sector Commander |
| Interviewee 9 | BA Entry Control | Ascot Drive | Senior Firefighter | 13 Years Experience as a BAECO |
| Interviewee 10 | BA Entry Control | Ripley | Watch Manager | 16 Years Experience as a BAECO (Retained) |
| Interviewee 11 | BA entry Control | Notts. Road | Firefighter | 2.5 Years Experience as a BAECO |
| Interviewee 12 | BA entry Control | Swodlincote | Firefighter | 2Years Experience as a BAECO (Retained) |
| Interviewee 13 | BA Wearer | Ascot Drive | Senior Firefighter | 15 Years Experience as a Firefighter |
| Interviewee 14 | BA Wearer | Long Eaton | Senior Firefighter | 13 Years Experience as a Firefighter |
| Interviewee 15 | BA Wearer | Ripley | Firefighter | 3 years experience as a Firefighter (Retained) |
| Interviewee 16 | BA Wearer | Swadlincote | Firefighter | 4 years experience as a Firefighter |

Appendix 4.7: Interview Guide for Goal Elicitation

Approximate Duration: Maximum 2Hrs. On average 1.5Hrs.

Type of Interview: Semi-structured - guided with pre identified scenario and task probes.

1. Scenarios to be used:

- Fire in one of the clothing shops located on the 2nd Floor of the Westfield Centre Derbyshire.
Date: Week Day, Time: 3.00 in the afternoon.
- Fire in one of the flats in 4th floor of Bath Street flats Community housing at Derbyshire.
Date: Weekday, Time: Midnight.
- Fire in one of the Nurses Quarters in 5th floor of Derbyshire Infirmary Nurses Quarters.
Date: Sunday, Time: 5 in the evening.
- Fire in Rolls Royce Nuclear Labs, Derbyshire.
Date: Weekday 10 in the Morning.

Discusses the four scenarios by explaining the situation described in the scenarios by step by step verbal walk through with the participant. Request any further clarification to be made. If there are any gray areas or misinterpretations, discuss and clarify such issues so that interviewee would finally have a clear mental picture of the situations being elaborated in the scenarios.

2. Explain what is expected to be captured during this interview. In this particular phase of interviews, in relation to the emergency response scope described in the four scenarios, it is primarily to capture the operational goals expected to achieve by the interviewee, driven by their job role responsibilities.

3. Explain what is meant by the name operational goal during emergency response and how it is different from routine physical tasks.

4. Thereafter, ask the interviewee to make an elaboration on the each task identified during previous phase of the GDIA. This could be support by incorporating each task in following type of open-ended questions:

- Why should you carry out this task?
- What is the motive of this task?
- What is the target you expect to achieve by doing this task?

Example: Assuming the task is *Talking to building inspectors from the local authority* (this is a task identified in the 1st Phase of the interviews made in relation to the Incident Commanders and Sector Commanders).

Specific Grand Tour Question could be formulated as below, so that can be put forward to the interviewees.

Question:

During our previous phase of the study we came across this task that as an IC you tend to talk to building inspectors from local authority or similar organisation , Could you please elaborate to me : why exactly you want to talk to such officers / what is the motive of talking to such officers / what is the objective or target you want to achieve by talking to such officers.

5. This inquiry can be grouped in to the time periods identified during the previous phase of interviews. For example, time periods could be:

- Goals till arrive at the incident (Initial Stage)
- During Operation (Development Stage)
- Closing (Finishing Stage) Stage

Therefore, open-ended specific grand tour questions comprise of tasks belonging to each of the above phase could be raised in the above order of time periods.

6. Depending on the specific job role and the findings of the task elicitation, above time periods can be different or further divide into sub categories.

7. Scenarios combined with the use of the identified tasks should always use to guide the interviewee to maintain the balance and to elicit as much as possible useful information related to goals.

8. Make sure the final outputs are independent from physical or mental tasks but describe the motives or mental demands expected from each job role. This can be achieved with the use of additional interview prompts, which motivate interviewees to look at the task based interview questions in a different dimension.

Such prompts could be:

Can you explain this particular situation further...?

Can you elaborate further on this?

What is your personal expectation or view point on this?

Could you give me an example?

Could you elaborate your own experience?

Could you explain any similar situation?

Apart from the above type of floating prompts, repeating the open-ended task questions in combination with the variations made to the original scenarios would expand their imagination boundaries and therefore, provide a comprehensive answer. Therefore, it is important to introduce variations to the scenarios when ever interviewees find it difficult to extend the tasks to identify its root goal or target.

9. Make sure at the end of the interview to obtain and get the elaboration on operational motives or goals behind each identified physical or mental job tasks for each job role.

Depending on the availability of time

10. Introduce changes to the incident location of the basic scenarios and request interviewees to elaborate on extensions or changes to their expectations and motives.

Example: By asking the question:

What would be the situation if similar type of fire occurred in the first floor of Derby Museum? Would there be any additional goals or target expected from you during the operations.

If interviewees ignore or give an inadequate answer to the above type of variations, putting forward a task that they are likely to carry out in that particular type of situation could be used.

Example: Task of talking to a responsible person from the Derby Museum.

In relation to the above tasks, raise the question: ***Why you want to talk to a person from Derby Museum in a fire situation.***

As elaborated above, introduction of scenario variations and floating alterations during the actual interviews enables to capture useful goals, which may not have been recognised with the first set of scenarios.

11. Efforts should be made to identify any priority in identified goals.
12. Efforts should be made to identify any essential goals.
13. Efforts should be made to identify any optional goals and conditions where they commonly become important.
14. Efforts should be made to identify any competing goals.
15. Relevant to each scenario, investigate whether there are any goals difficult to achieve by carrying out the identified tasks.
16. If answer is “Yes” for above, inquire how fire fighters manage to achieve them.

At the end of each interview, it is important to mention the expected outcome of the interviews and prompt the need of having the next round of interviews to get the information requirements and therefore, request continuous support of the interviewees for the future interview phases.

Appendix 4.8: Sample of Goal Fragments for the Job Role Incident Commander

4.8.1 Category 1 goal fragments exclusively represent the top most goals of the Job Role Incident Commander

| Fragment Ref: | Interviewee 1 | Interviewee 2 | Interviewee 3 | Interviewee 4 | Fire and Rescue Policy and Procedure Documents | Observation of Live Scenarios / Trainings |
|---------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1.1 | If you ask a priority, I would first look for the safety of my crews, then saving lives of other general public, next comes the building and rest of the property and valuables, finally environment. These days we consider environment as very important consideration. As described in our procedure bible, we try to save life of casualties and general public as much as possible but we may regard safety of fire fighters first. | As an incident commander my first duty would be to protect my fire fighters. | Health and safety of people and my team followed by physical and environmental property comprises our top most aim. Any other thing will have to follow these priorities. Health and safety of my crews become the main responsibility as a IC | As an incident commander I have to first look after my crews | In a highly calculated way, firefighters: <ul style="list-style-type: none"> will take some risk to save savable lives, may take some risk to save savable property, will not take any risk at all to try to save lives or properties that are already lost. (Incident Command Fire Service Manual,2008) | |
| 1.2 | | | | | | |
| 1.6 | | After the health and safety of my crews, next priority would definitely be the casualty due to the incident itself and the general public affected due to the incident | | | | Casualty and General public being handled and served differently. (Incident Command Training – Field Note Ref: 1.5, Rolls Royce fire training, Field Note Ref: 1.9) |
| 1.7 | Depending on the situation we may take some risk to save the property, environment or other valuables of the client. But we may not risk our life to do that | Sometimes if there is no life threat we may try to protect the environment as well as the valuable or savable property and related items | | | | IC shows concerns with regard to the environment belonging to the incident premises as well as to the nearby surroundings (Rolls Royce fire training, Field Note Ref: 1.6) |

4.8.2 Category 3 goal fragments exclusively represent the top most goals of the Job Role Incident Commander

| Fragment Ref: | Interviewee 1 | Interviewee 2 | Interviewee 3 | Interviewee 4 | Fire and Rescue Policy and Procedure Documents | Observation of Live Scenarios / Trainings |
|---------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------|------------------------------------------------|------------------------------------------------------------------------------------------------------------------------|
| 3.1 | As an incident commander arrives at an incident you want to ensure to make an appropriate commitment but not a haphazard commitment. It should be a proper entry. | If realize current commander is in control I will decide not to interfere but to become an | As a senior officer who is asked to report to a particular incident, proper commitment | Appropriate commitment would be one of the top-level objectives as an IC. As soon as I get my advice to go to a | | Senior Officers take their time before commit as IC. They spend some time talking to people , observing ,going through |

| | | | | | |
|--|-------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------|---------------------------|--------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------|
| | For me the commitment process starts from the moment I receive my role call. From that point on wards all the things I do help me to commit myself smoothly | observer. | as an IC is important ... | particular incident first thing that comes to my mind is that I should commit myself smoothly as soon as possible. | information (Incident Command Training – Field Note Ref: 1.3, Westfield fire training – Field Note Ref: 1.5, University of Derby – Field Note Ref: 1.6) |
|--|-------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------|---------------------------|--------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------|

4.8.3 Category 4 goal fragments exclusively represent the top most goals of the Job Role Incident Commander

| Fragment Ref: | Interviewee 1 | Interviewee 2 | Interviewee 3 | Interviewee 4 | Fire and Rescue Policy and Procedure Documents | Observation of Live Scenarios / Trainings |
|---------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 4.1 | It will always be in my mind as an IC who suppose to close an Incident, to make sure that I have done enough to carry out proper post incident considerations. | One of the important responsibilities as an incident commander would be the post incident considerations | Look and consider what happened during the incident has become one of the most important goals of the IC. As the IC I should make arrangements to assess the post incident considerations. It is my duty to make sure vital information is collected, preserved and protected. | As an incident commander it is very important to have a debriefing to ensure the Post incident considerations | The IC must, at the earliest convenient time, attempt to assess what the post-incident considerations might be. (Incident Command Fire Service Manual,2008) | Immediate post incident debrief conducted by the IC (West field fire training - Field Note Ref: 1.15, Rolls Royce fire training - Field Note Ref: 1.13, University of Derby – Field Note Ref: 1.12) |
| 4.3 | As an IC I may have to transfer my duties to a senior officer as when things get complex or complicated | Similar to my own commitment, some other senior officer may take over from me. This handing over process is one of the important goals of mine as an IC | | It is one of the crucial target of mine to properly transfer my job to another senior officer | | When the incident develops several ICs takeover by substituting experienced officers to replace junior officers (Incident Command Training – Field Note Ref: 1.4, Westfield fire training – Field Note Ref: 1.7, University of Derby – Field Note Ref: 1.5) |

4.8.4: Category 1 goal fragments exclusively represent tertiary and lower-level goals of “Ensure Appropriate Commitment as an IC”

| Fragment Ref: | Interviewee 1 | Interviewee 2 | Interviewee 3 | Interviewee 3 | Fire and Rescue Policy and Procedure Documents | Observation of Live Scenarios / Trainings |
|---------------|---------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------|----------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------|-------------------------------------------|
| 1.13 | I feel what is happening due to our involvement is different from the contextual Incident know how ... I don't think first one is part of the other one | I don't think my desire of knowing our operations is part of having an accurate picture. Actually picture is purely on the context ...but operations... it is all about our involvement..... | | | | |
| 1.15 | Incident related picture can be better made if you combine your own observations with the knowledge gain from other external resources. | | | Incident picture you try to build on the way or just after arrival is a mixture of your own knowledge and knowledge gain through other means | | |

4.8.5: Category 2 goal fragments exclusively represent tertiary and lower-level goals of “Ensure Appropriate Commitment as an IC”

| Fragment Ref: | Interviewee 1 | Interviewee 2 | Interviewee 3 | Interviewee 4 | Fire and Rescue Policy and Procedure Documents | Observation of Live Scenarios / Trainings |
|---------------|------------------------------------------------------------------------------|----------------------------------------------|-----------------------------------------------------|---------------------------------------------|------------------------------------------------|-------------------------------------------|
| 2.7 | We like to make a better picture before coming to the incident. Specially on | Good picture before reaching the incident is | We always try to build a picture in our head on our | Key would be to build a picture accurate as | | |

| | | | | | | |
|-------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| | the context in and around the incident.....and make sure we have enough knowhow related to the incident context | essential | way. We always want this picture to become closer as possible to the actual incident. | possible before arrival and before committing as the IC | | |
| 2.8 | It is important to make sure you have enough knowledge about the incident ...as early as possible ...importantly before you commit as an IC. you see this helps me to build a clear picture of the incident | I like to receive as much as possible various type of incident related information | To build a picture before arrival I like to improve my knowledge related to current situation of the incident.what I meant is the context of this particular incident | | | |
| 2.9 | I constantly look for appropriate operational instructions, procedures relevant to the specific incident. | It is important to go through the specific procedures, operational activities suitable to be carried out | It is always better to look at specific operational procedures specific or unique to the incident, if there is any | | All major risk locations will have incident specific procedure notes containing risks, hazards. (West Yorkshire Category 3 and 4 Operational Risk Reviews, 2007, Derbyshire Category 3 and 4 Operational Risk Reviews, 2005, Incident Command Fire Service Manual, 2008) | When receive the role call IC show need and concern to access specific category 3 or category 4 operational risk reviews. (Westfield fire training – Field Note Ref: 1.1, University of Derby – Field Note Ref: 1.2) Immediately upon arrival senior officers ask for relevant operational risk reviews from command support (Incident Command Training – Field Note Ref: 1.5) |
| 2.10 | I always look for appropriate incident specific knowledgeeven before we arrive at the incident. ...this may be some unique local knowledge | | | | | When receive the role call IC show some concerns as he is not familiar with the incident site (University of Derby – Field Note Ref: 1.1) |
| 2.11 | I think before committing yourself, and the building itself have to be referred for better decisions..... specially to ensure better navigation to and around the incident | I really look for the maps and stuff ...I want to make sure I can get to the incident site smoothly and quickly.... | We like to ensure proper access to maps of the incident itself and the area aroundidea is you do better job after reaching the incident | I like to know where exactly the access to the incident and the rendezvous convey through an accurate mapgetting it to know them accurately is crucial...I want to make sure to have proper navigation.... | | When receive the role call the immediate worry of the IC is to get to the incident as quickly and safely as possible. Immediately try to look for incident related maps (Rolls Royce – Field Note Ref: 1.3) |
| 2.23 | | We can't survive without the knowledge of casualty. I always start pushing myself to figure out about casualty as soon as I receive my role call. | | Even before arriving at the incident I like to make sure to have better knowhow about the possible causalities at the incident | | |

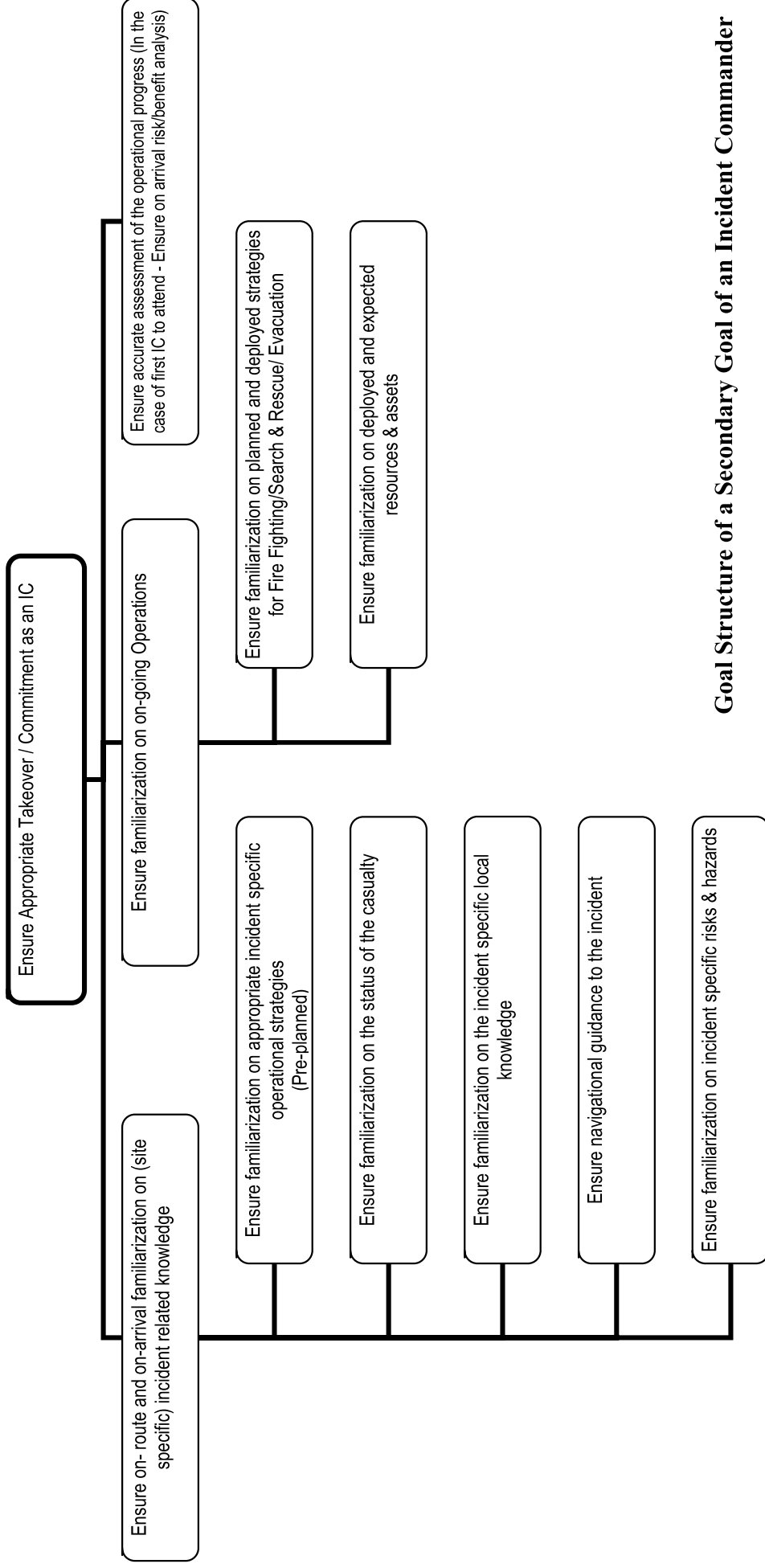
4.8.6: Category 3 goal fragments exclusively represent tertiary and lower-level goals of “Ensure Appropriate Commitment as an IC”

| Fragment Ref: | Interviewee 1 | Interviewee 2 | Interviewee 3 | Interviewee 4 | Fire and Rescue Policy and Procedure Documents | Observation of Live Scenarios / Trainings |
|---------------|---------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 3.12 | One of our objectives would be to circle around the incident and make our own observations by circling around | Like to have proper observation of my own. if possible observation of whole incident | Always ensure my own knowledge gathering by circling the incident by my self | Apart from the knowledge I want to have my own knowledge gathering by circling the incident around | | New IC circles around the incident observing details before take over. (Rollis Royce – Field Note Ref. 1. 4, Westfield fire training – Field Note Ref: 1.4) |
| 3.13 | Incident commander must clearly know what is happening at the incident.....so far due to the involvement of fire and rescue ... | I must ensure to get an accurate feedback on the operations being carried out and already completed..... It is important to make sure to have a measure of the progress of the operations | I like to have a clear understanding of operations being carried out so far..... Being a senior officer, I want to know the performance level of present IC as accurate as possible | As an IC intends to take over I want know the deployed operational process and control measure Ensure what is the operational progress, it is important before take over to assess this. | | IC is keen to clearly understand the Operational information prior to take over(Incident Command Training – Field Note Ref: 1.8) |
| 3.14 | Before take over it is important to make sure to assess the operational progress so far.....accurately as much as possible | It is important for me to ensure update myself with as much as possible accurate knowledge about the casualty | As an IC I should have a good understanding about the casualty | Before assume duty it is important somehow to build my confidence on the casualty related knowledge | | It seemed to be the main concern of the senior officer before committing, as he is desperate to get some confirmed information about the possible causalities in the danger area (Westfield fire training – Field Note Ref: 1.6) |
| 3.19 | Before commit myself I want to familiarize with the status of the possible casualties. | | | | | |

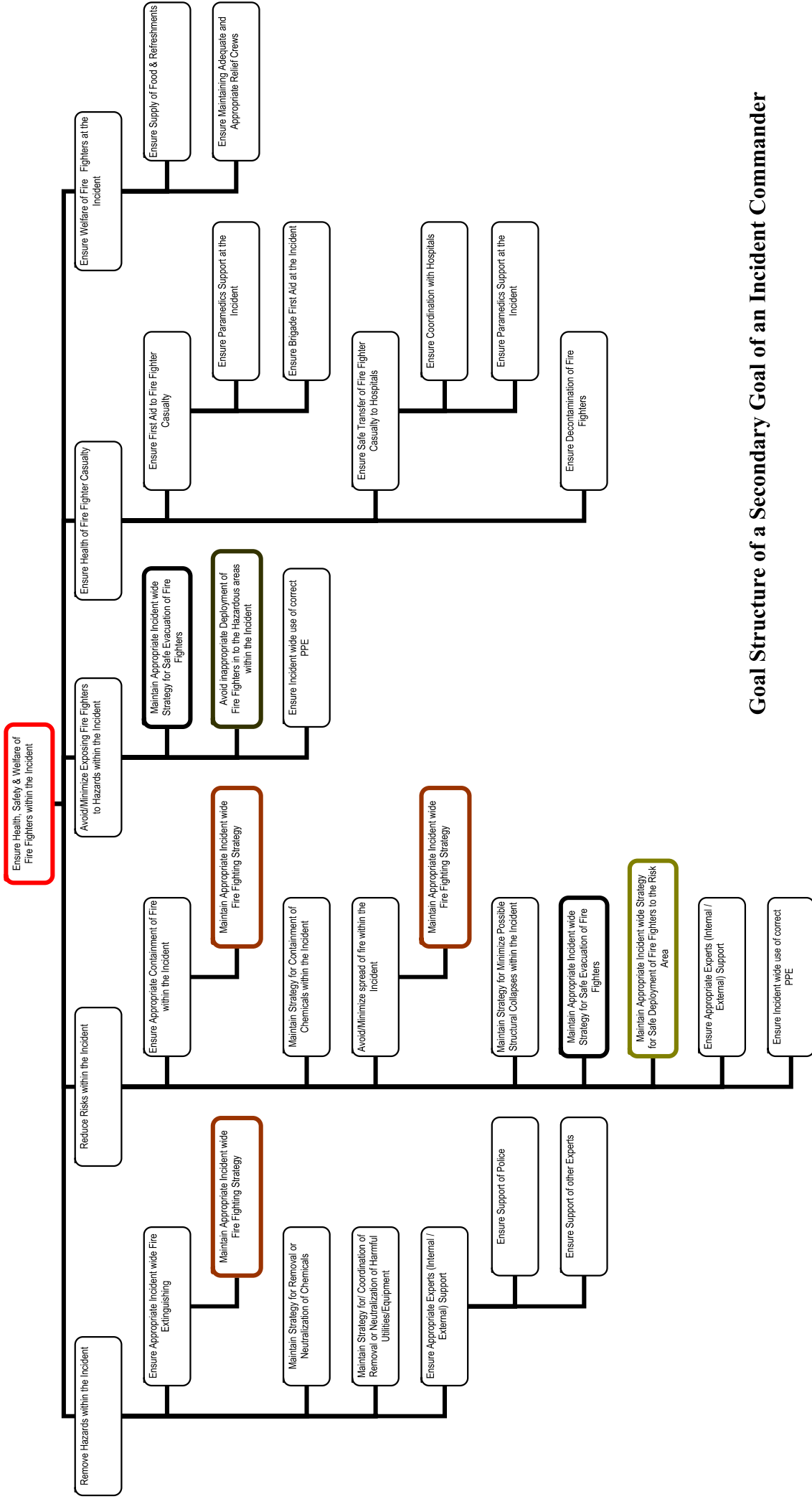
Appendix 4.9: List of SMEs selected for the Validation of Goal Structures

| Reference | Job Role | Fire Station | Designation | Experience |
|---------------|--------------------|---------------------------------------------------------------------------|---------------------------------------------|-------------------------------------------------------------------------------------|
| Interviewee 1 | Incident Commander | Ascot Drive Derbyshire | Area Group Manager | 15 Years Experience as an IC with real-time experience in large building fires. |
| Interviewee 2 | Incident Commander | Old Hall, Training School Derbyshire | Command Training Manager | 12 Years experience as an IC and Incident Command Training officer |
| Interviewee 3 | Incident Commander | Incident Command Training School, Market Harborough, Leicestershire | Specialist Training Instructor for IC teams | 10 Years experience as IC and Incident Command Training Officer |
| Interviewee 4 | Incident Commander | Meridian Park Fire Station, Leicestershire | Specialist Training Instructor for IC teams | 17years experience as IC and Incident Command Training Officer |
| Interviewee 5 | Incident Commander | Head Office, Leicestershire Fire and Rescue, Glenfield, Leicestershire | Incident Command Systems Project Manager | 20 Years experience as IC and Incident Command Training officer |
| Interviewee 1 | Sector Commander | Ascot Drive Fire Station, Derbyshire | Station Manager | 20 Years Experience as an SC with real-time experience in large building fires. |
| Interviewee 2 | Sector Commander | Old Hall, Training School Derbyshire | IC Training Instructor | 10 Years experience as an Sector Commander and Incident Command Training officer |
| Interviewee 3 | Sector Commander | Incident Command Training School, Market Harborough, Leicestershire | Training Instructor for IC teams | 12 Years experience as SC and Incident Command Training Officer |
| Interviewee 4 | Sector Commander | Meridian Park Fire Station, Leicestershire | Watch Manager | 15years experience as SC and with real-time experience in large building fires. |
| Interviewee 5 | Sector Commander | Head Office, Nottingham Fire and Rescue, Bestwood Lodge Arnold Nottingham | Watch Manager | 20 Years experience as SC with real-time experience in large building fires. |
| Interviewee 1 | BA entry Control | City North Fire Station, Nottinghamshire | Watch Manager | 22 Year Experience as BAECO with real-time experience in large building fires. |
| Interviewee 2 | BA entry Control | Loughborough Training and Development Centre | BA Training Manager | 20 Years of Experience as BAECO and BA Training Instructor |
| Interviewee 3 | BA entry Control | Derbyshire BA School | BA Training Instructor | 17 Years of Experience as BAECO and BA Training Instructor |
| Interviewee 1 | BA Wearer | Loughborough Training and Development Centre | BA Training Instructor | 15 Years Experience as BA Wearer and BA Training Instructor |
| Interviewee2 | BA Wearer | Derbyshire BA School | BA Training Instructor | 20 Years of Experience as BA Wearer and BA Training Instructor |
| Interviewee 3 | BA Wearer | City South Fire Station Nottinghamshire | Crew Manager | 20 Years Experience as BA Wearer with real-time experience in large building fires. |

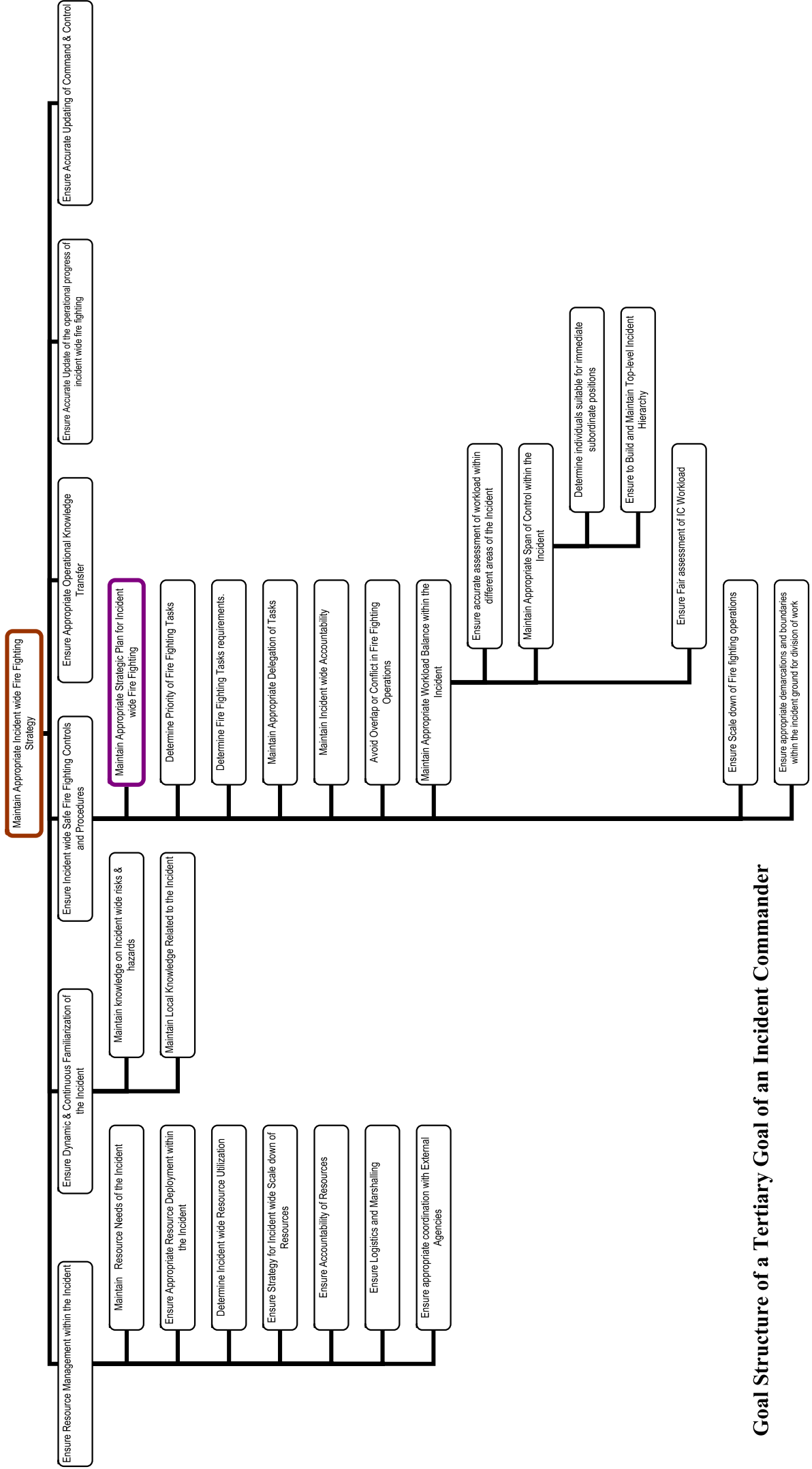
Appendix 4.10: A Sample of Validated Goal Structures



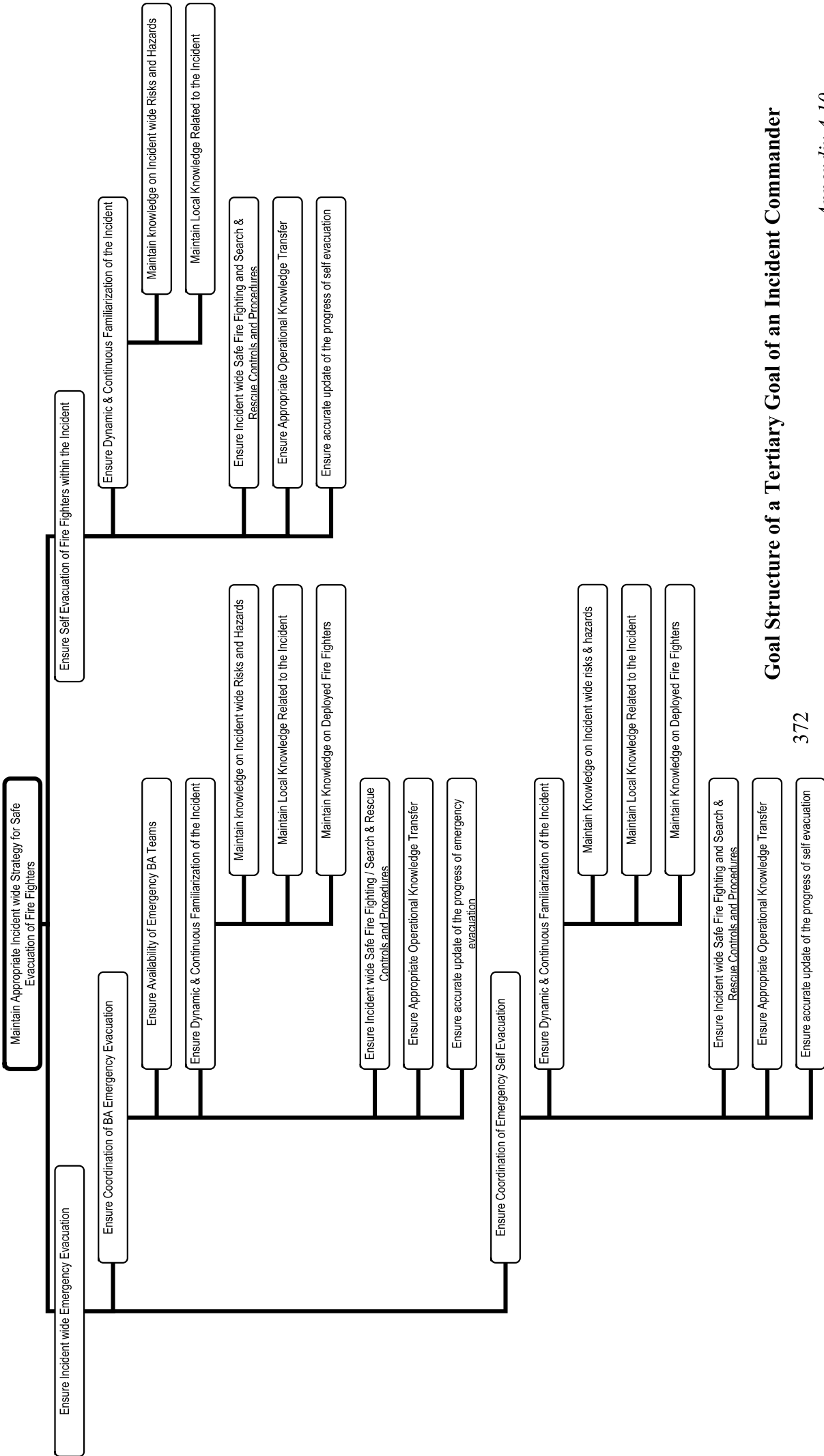
Goal Structure of a Secondary Goal of an Incident Commander



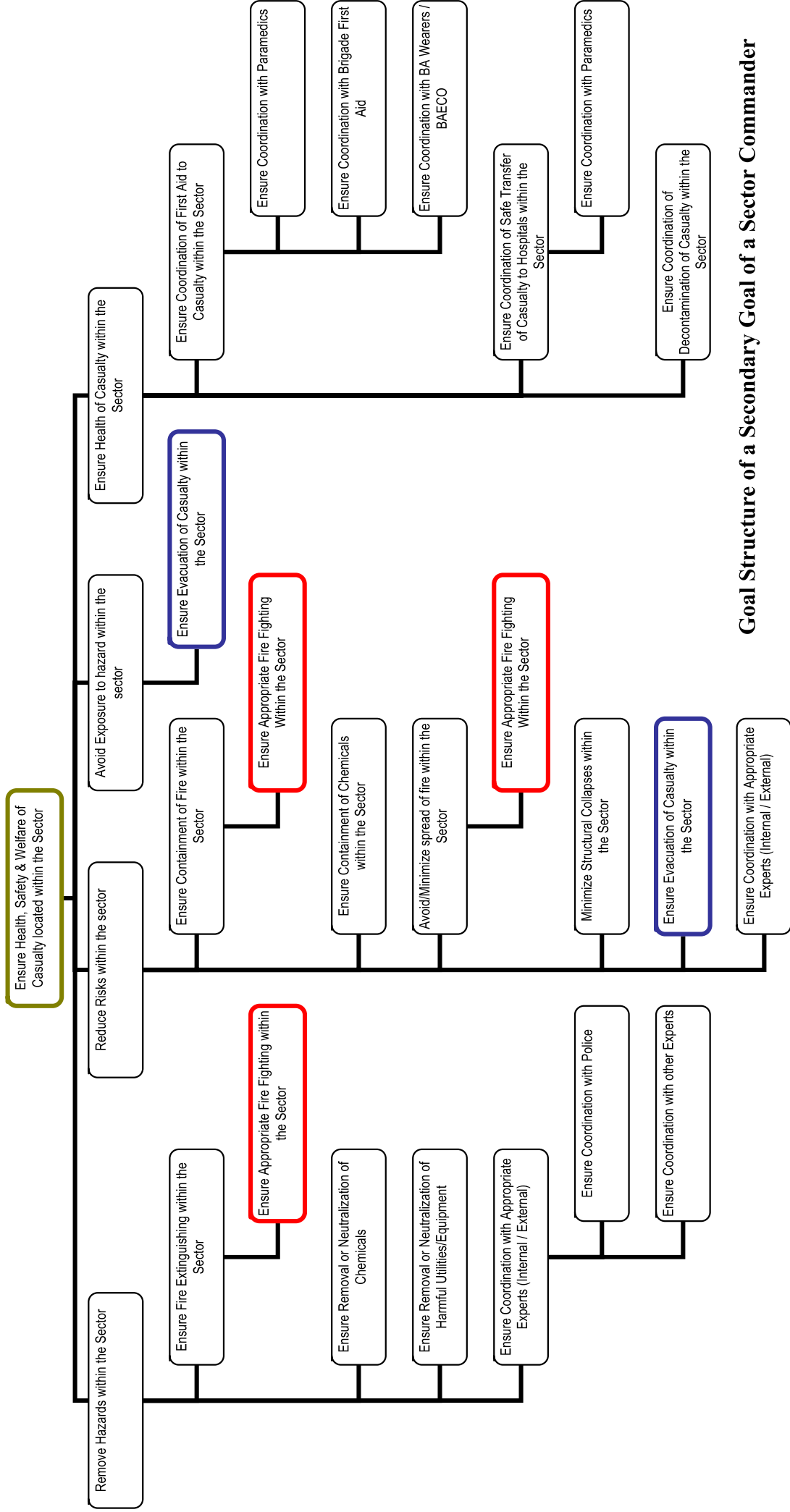
Goal Structure of a Secondary Goal of an Incident Commander



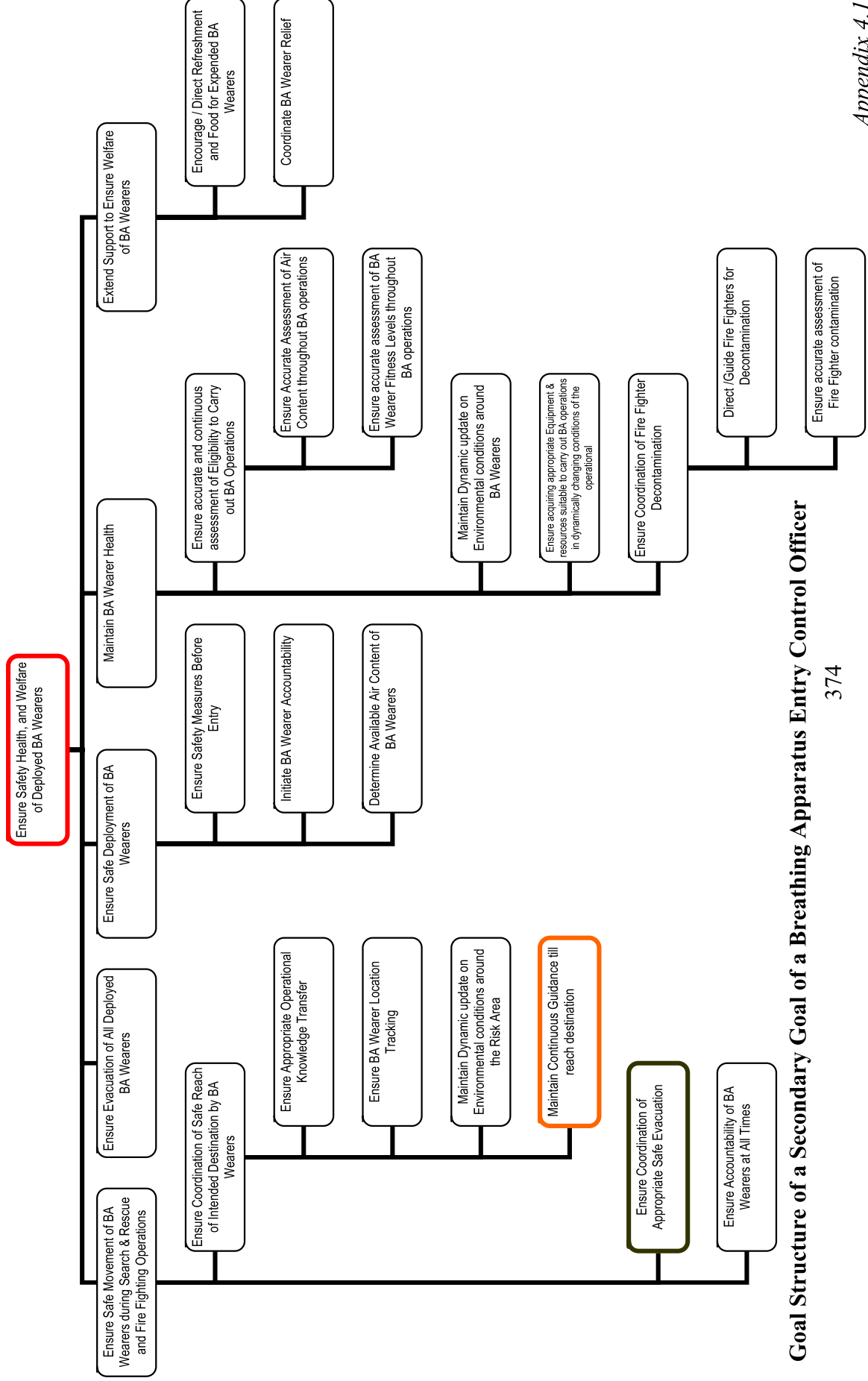
Goal Structure of a Tertiary Goal of an Incident Commander



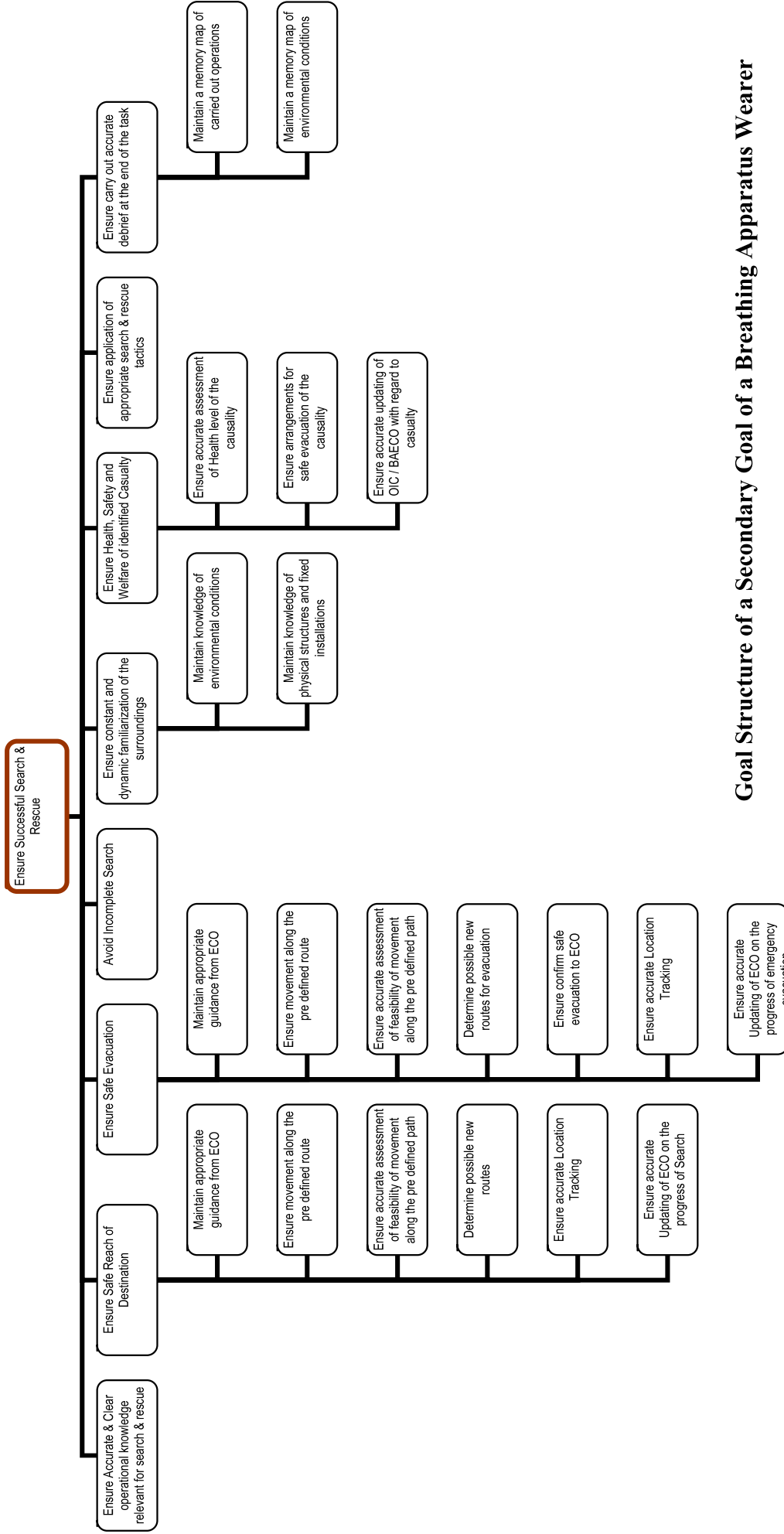
Goal Structure of a Tertiary Goal of an Incident Commander



Goal Structure of a Secondary Goal of a Sector Commander



Goal Structure of a Secondary Goal of a Breathing Apparatus Entry Control Officer



Goal Structure of a Secondary Goal of a Breathing Apparatus Wearer

Appendix 4.11: List of SME's selected for the Decision and Information Requirements Elicitation Interviews

| Reference | Job Role | Fire Station | Designation | Experience |
|----------------|--------------------|--------------|---------------------|------------------------------------------------------|
| Interviewee 1 | Incident Commander | Ascot Drive | Area Group Manager | 15 Years as an IC Bronze and Silver level IC |
| Interviewee 2 | Incident Commander | Reply | Station Manager | 18Year as an IC Bronze (Retained) |
| Interviewee 3 | Incident Commander | Swadlincote | Station Manager | 3 Years experience as a Incident Commander |
| Interviewee 4 | Incident Commander | Old Hall. | Station Manager | 4 Years experience as a Incident Commander |
| Interviewee 5 | Incident Commander | Notts. Road | Area Group Manager | 16 Years of Experience as a Incident Commander |
| Interviewee 6 | Sector Commander | Notts. Road | Station Manager | 20 Year Experience as a Sector commander |
| Interviewee 7 | Sector Commander | Swadlincote | Watch Manager | 15 Years Experience as a sector Commander (Retained) |
| Interviewee 8 | Sector Commander | Ascot Drive | Watch Manager | 5 Years Experience as a Sector Commander |
| Interviewee 9 | Sector Commander | Ascot Drive | Senior Fire Fighter | 2 Year Experience as a Sector Commander |
| Interviewee 10 | Sector Commander | Ripley | Watch Manager | 10 Years Experience as a Sector Commander (Retained) |
| Interviewee 11 | BA Entry Control | Ascot Drive | Senior Fire fighter | 13 Years Experience as a BA ECO |
| Interviewee 12 | BA Entry Control | Ripley | Watch Manager | 16 Years Experience as a BA ECO (Retained) |
| Interviewee 13 | BA entry Control | Notts. Road | Fire fighter | 2.5 Years Experience as a BAECO |
| Interviewee 14 | BA entry Control | Swodlincote | Fire fighter | 2Years Experience as a BAECO (Retained) |
| Interviewee 15 | BA entry Control | Old Hall | Senior Firefighter | 10Years Experience as a BAECO |
| Interviewee 16 | BA Wearer | Ascot Drive | Senior Fire fighter | 15 Years Experience as a Firefighter |
| Interviewee 17 | BA Wearer | Ascot Drive | Senior Fire fighter | 13 Years Experience as a Firefighter |
| Interviewee 18 | BA Wearer | Ripley | Firefighter | 3 years experience as a Firefighter (Retained) |
| Interviewee 19 | BA Wearer | Swadlincote | Firefighter | 4 years experience as a Firefighter |
| Interviewee 20 | BA Wearer | Notts. Road | Senior Firefighter | 9 Years Experience as a Firefighter |

Appendix 4.12: Interview Guide for Information Elicitation

Approximate Duration: Maximum 2 Hrs. On average 1.5Hrs.

Type of Interview: Semi-structured - guided with pre identified scenario and goal probes.

1. Scenarios to be used:
 - Fire in one of the 2nd floor clothing shops in Westfield Centre Derbyshire.
Date: Week Day Time: 3.00 in the afternoon.
 - Fire in one of the flats in 4th floor of Bath Street flats Community housing at Derbyshire.
Date: Weekday, Time: Midnight.
 - Fire in one of the Nurses Quarters in 5th floor of Derbyshire Infirmary Nurses Quarters.
Date: Sunday, Time: 5 in the evening.
 - Fire in Rolls Royce Nuclear Labs, Derbyshire.
Date: Weekday 10 in the Morning.
2. All others, except participants from the previous rounds of the interviews, should be briefly introduced to the aims and objectives of this study.
3. As in the previous occasions scenarios will be sent to the participants few days before the actual interview and request them to get familiarised. This will be not practiced with the participants who already participated in the interviews. This is purposefully done to avoid time being spend on detail explaining of the scenarios. Yet at the beginning of the interviews, scenarios will be discussed briefly and clarifications will be made. Therefore, participants are expected to use the memory of the scenarios during answering the questions. During the brief introduction, participants who are not thorough with the scenarios will be identified. These participants will be re introduced to the scenarios and elaborated in detail.
4. Explain what you are looking to discuss during this interview (To elicit decision requirements and required information of each job role).
5. Participants will be requested, First, to focus their answers to describe decisions they want to make, problems they want to solve or questions they want to answer in order to achieve the specific goal or objective being discussed. Second, they will be asked to describe their information requirements leading to make such decisions, solve such problems or questions to be answered.

6. Depending on the allocated time, effort will be made to elaborate each identified goal starting from the bottom level sub goals. With the use of the scenario probes participants will be requested to describe their decision requirements, problems to solve when they want to achieve such a goal.
7. When participant describe the decisions they want to make, questions they want to answer or problems they wants to solve, they will be further probed to capture the information requirement for such decision or problem solving.
8. As there are many repeating sub goals they should not be separately inquired. Yet in order to capture comprehensive answers, higher-level goals will be used as prompts to identify any variation in participant's decision-making and information requirements of the individual lower-level goals.
9. As described above, goals will be formulated in such a way that they can act as specific grand tour interview questions. Further, immediate higher-level goals will be used as useful planned interview prompts to improve the answers. In addition, when necessary, open-ended questions will also be raised with the support of the above items.

As an example, below illustrates how a specific grand tour question is formulated from a selected content (item) [Identified goals of the previous interviews].

Selected Interview Guide Content (Item):

Ensure Dynamic & Continuous Familiarization of the Incident

- *Ensure continuous flow of casualty related know how / Ensure receipt of continuous knowledge of casualty status*
- *Ensure Appropriate Strategy for Search & Rescue within the Incident*
- *Maintain Appropriate Incident wide Strategy for Safe Deployment of Fire Fighters to the Risk Area*
- *Avoid inappropriate Deployment of Fire Fighters in to the Hazardous areas within the Incident*

Question 1

*As an IC you may wants **to ensure continuous casualty related know how** this would be essential when you want **to dynamically familiarize with the incident**. In order to reach this particular objective, could you please elaborate what are the **decisions you want to make / questions to me answered / problems to be solved?***

If a participant finds it difficult to describe an answer, and then use the top-level goals in such a way that it become a prompt so that participants can better illustrate their answer. In this particular example, a planned prompt can be developed as:

Planned Secondary Prompt

*“Reaching these goals could be very important as it will help IC to carry out better **search and rescue or it will help IC to avoid inappropriate deployment of***

fire fighters or safe deployment of fire fighters in to the Risk area.” Therefore, finally these decisions should support you to reach this higher-level objective.

If answer is satisfactory and elaborative, ask the next question. Otherwise, should consider the use of additional interview prompts, which motivate interviewees to look at the situation with different view point or motivate to describe either decisions or information with clearer elaborations.

Such prompts could be:

Can you elaborate further on this?

Could you give me an example?

Could you elaborate your own experience?

Question 2

*If you need to solve such problems/ to make such decisions/answer such questions what type of **information** you need or looking for?*

As the above for each and every item or a content (goals), specific grand tour questions and secondary planned prompts should be formulated at the time of the interview.

Appendix 4.13: Decision and Information Fragments and Interpretation of Decision and Information Relevant to the Goal “Ensure Familiarization on the Status of the Casualty”

Theme: Sub goal 3.1.2 - Ensure familiarization on the status of the casualty Decision-making Requirements

| Interviewee 1 | Interviewee 2 | Interviewee 2 | Interviewee 2 | Interviewee 4 | Interviewee 5 | References/Observations | Final Interpretation |
|----------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|----------------------|
| I quickly need to come to a conclusion and decide whether we can find any casualty within the risk area. | I have to decide whether there are people to be rescued | Is everybody evacuated or accounted for, this is a question to be answered | We have to clearly make the decision on the existence of casualty | I have to always verify in my head whether there are any possible people inside that building | Ask O.I.C. about possibility of casualty inside the building (Westfield fire training – Field Note Ref: 1.6) | <i>What is the possibility of locating casualty and in what numbers?</i> | |
| I have to answer the question “ what sort of casualty can we find in this premises” | One question in my head may be to realize type of casualty | | | Can I clearly figure out what sort of people we may have to rescue | | <i>What type of casualty we can expect to find?</i> | |
| Most importantly we may have to decide how occupants or casualty are moving inside the risk area | Before start any search operations I want to answer the question of “How they move around and where we can find the casualty.” | | It is important as a IC to decide what sort of movement behaviour we can expect from the occupants or casualty | | | <i>What is the movement behaviour of casualty?</i> | |
| I like to make a assessment on the condition of the people inside | What can be the condition of people to be rescued | | It is important for me to decide the expected condition of the casualty | | | <i>What can be their Condition?</i> | |
| It is important to confirm whether we are performing well in our rescue operations | I like to know the progress of our rescue efforts. | To know the status of evacuation or rescue of people is crucial for me | | | | <i>What is the level of success with regard to rescue and evacuation operation?</i> | |

Information Requirements

| Interviewee 1 | Interviewee 2 | Interviewee 2 | Interviewee 4 | Interviewee 5 | References /Observations | Final Interpretation |
|-------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------|---------------|----------------------------------------------------------------------------------|--------------------------|---------------------------------------------------------------------------------------------------------------|
| To answer my question I like to know the approximate number of casualty being reported | List of casualty to be rescued | Number of casualty to be rescued | | | | Number of reported casualty |
| Break down of casualty expected , males, females, children | Types of casualty | Classification of casualty | | | | Type of occupants/casualty <ul style="list-style-type: none"> Male/Female/Children/Disabl e |
| I like to have information of the possible movement of casualty with the progress of fire | It is always good if we have the information on how casualty being moved from place to place | Casualty walkabouts as when incident escalates | | | | Movement of Casualty |
| | Present location or coordinates of casualty would be ideal information | | | Room or area where you can find the people to be rescued | | Whereabouts of Casualty |
| | Expected casualty injuries | | | Nature of injuries possible | | Nature of Injuries and Level of Contamination |
| Number of rescues so far and further rescue needs | So far how many rescues being done and to be done | Rescue efforts need to be carried out and if possible rescues done till present | | | | Number rescued and to be rescued |
| First aid provided could be important | | | | On-site treatment provided | | Details of first aid provided |
| Currently where are the casualties | Can I get the location on a map | Location on a map | | | | Location of Casualty |
| Changes possible to the current location of the casualty | Very useful if I know the changes that can be possible for the casualty locations | | | As the new IC it would be great if I knew possible new movements of the casualty | | Possible changes to the present location of casualty |

Appendix 4.14: Interpretation of Decision and Information Relevant for the Sub Goals of “Ensure Appropriate Takeover / Commitment as an IC”

Theme: Sub goal 3.1.1- Ensure familiarization on appropriate incident specific operational strategies

Decision-making Requirements

| |
|-----------------------------------------------------------------------------------------------------------|
| Final Interpretation |
| <i>What is the classification of the building?</i> |
| <i>What is the correct generic procedure for this type of building suit for this particular incident?</i> |

Information Requirements

| |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Final Interpretation |
| <i>Name and address of the building</i> |
| <i>Building reference</i> |
| <i>Building Information</i> |
| <ul style="list-style-type: none"> ○ <i>Number of floors</i> ○ <i>Purpose of Building Use</i> ○ <i>Building Materials</i> ○ <i>Special Type of floors (Basement/Cinema/Car Parks)</i> |
| <i>Type of occupants/casualty</i> |
| <i>Location of Important Surrounding Buildings/Properties</i> |
| <i>Building and incident specific tactics & procedures</i> |
| <i>Standard operating procedures</i> |

Theme: Sub goal 3.1.3: - Ensure familiarization on the incident specific local knowledge

Decision-making Requirements

| |
|---------------------------------------------------------------------------------------------------------------------------------|
| Final Interpretation |
| <i>What type of fixed installations and special equipments expected at the incident?</i> |
| <i>What is the current weather and will there be any changes to the wind/ weather patterns of the surrounding?</i> |
| <i>What are the vulnerable buildings within the proximity and their impact from / to this incident?</i> |
| <i>What are the vulnerable or valuable items to be rescued/evacuated/contained?</i> |
| <i>Decide whether buildings are safe to carry out the fire fighting operations or search and rescue or any other operation?</i> |
| <i>What type of population profile expected around the incident vicinity?</i> |

Information Requirement

| |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Final Interpretation |
| <i>Details Sprinklers/Ventilators (Type / Specification)</i> |
| <i>Details of unusual features such as security doors</i> |
| <i>Details of Fire fighter lifts and shafts.</i> |
| <i>Details of the Sprinklers/Ventilators</i> |
| <ul style="list-style-type: none"> ○ <i>Where it is installed</i> ○ <i>Where to locate the controls</i> ○ <i>Where it currently in operation</i> |
| <i>Location of Unusual features (Ex. External security doors)</i> |
| <i>Location of Premises information box</i> |
| <i>Hydrants and Riser Details (Type/Specification)</i> |
| <i>Location and Status</i> |
| <i>Details of vulnerable organizations nearby</i> |

| |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <ul style="list-style-type: none"> ○ Type (schools, power stations, fireworks/explosives) ○ Process details ○ Number of occupants ○ Availability of occupants ○ Location the building and its occupants |
| List and location of items to be salvaged/ evacuated/contained |
| Building Safety <ul style="list-style-type: none"> ○ Type of Building Material (Walls, Floor, Roof) ○ Age of the Building ○ Location/ Signs of Cracks ○ Location Signs of Collapse |
| Current Weather Conditions |
| Wind Patterns |
| Weather forecast including wind direction of the vicinity |
| Population around the incident and Population Profile |
| Domestic House Profile |

Theme: Sub goal 3.1.4 - Ensure navigational guidance to the incident

Decision-making Requirements

| |
|-------------------------------------------------------------|
| Final Interpretation |
| How can we reach the incident as soon as possible? |
| What is the best path to the incident? |
| Is the area heavily populated? |
| What would be the traffic conditions? |
| What is the/ How to get proper access and rendezvous point? |

Information Requirements

| |
|------------------------------------------------------------|
| Final Interpretation |
| On route traffic information |
| Present Location |
| Distance to destination |
| Population around the incident |
| Location of Access points to the incident/Rendezvous Point |
| Possible (new) Routes and Distance to travel |
| Traffic Forecast |
| Route to destination from current location |
| Post Code |
| Street and Address |
| Time to Destination |
| Vulnerable Routes |

Theme: Sub goal 3.1.5: - Ensure familiarization on incident specific risks & hazards

Decision-making Requirements

| |
|---------------------------------------|
| Final Interpretation |
| What are the risks and hazards? |
| What is their behaviour and progress? |

Information Requirement

| |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Final Interpretation |
| Possible risks and hazards |
| Temperature near and surrounding area of the hazards |
| Hazmat Data <ul style="list-style-type: none"> ○ Constituent, reaction with others, neutralizers, rate contamination, types of decontaminants |

| |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <ul style="list-style-type: none"> ○ Required level of PPE to work with |
| <p><i>Building Structure</i></p> <ul style="list-style-type: none"> ○ Profile of the floors ○ Roof Work ○ Floor Work ○ Inner and outer wall materials |
| <p><i>Structure of the Building (Graphical 3D view)</i></p> |
| <p><i>Location of risks and hazards</i></p> <ul style="list-style-type: none"> ○ the fire, chemicals, explosives ○ building collapses ○ Utilities like gas and electricity |
| <p><i>Location of Gas and Electricity switch Panels</i></p> |
| <p><i>Spread of Fire</i></p> <p><i>Spread of Chemicals other hazards</i></p> <p><i>Profile of the Temperature/smoke</i></p> <p><i>Profile of the wall temperature</i></p> <p><i>Forecast of fire/smoke/temp</i></p> <p><i>Forecast of spread of chemicals and other hazards</i></p> |
| <p><i>Amount of water being used on the walls and duration</i></p> |

Theme: Sub goal 3.2.1 - Ensure familiarization on planned and deployed strategies for Fire Fighting/Search & Rescue/ Evacuation

Decision Requirement

| |
|--------------------------------------------------------------|
| Final Interpretation |
| <i>What is the current level of operations going on?</i> |
| <i>What is the impact of current and planned operations?</i> |

Information Requirement

| |
|-------------------------------------------------------------------------------------|
| Final Interpretation |
| <i>Number of deployed officers & crews</i> |
| <i>Tactical Mode of each sector</i> |
| <i>Major operations carried out in each sector</i> |
| <i>Who is the IC at the moment</i> |
| <i>Number of Sectors</i> |
| <i>Areas of the building where different operations being carried out</i> |
| <i>Current Incident Hierarchy</i> |
| <i>Location and Movement of Crews in operation</i> |
| <i>Operations planned for the immediate future</i> |
| <i>Expected results from planned operations</i> |
| <i>Sectorisation Plan (Showing sector/ Marshalling Points/ Bridge Head / ECPS)</i> |

Theme: Sub goal 3.2.2 - Ensure familiarization on deployed and expected resources & assets

Decision Requirement

| |
|--------------------------------------------------------------------------------|
| Final Interpretation |
| <i>What is the progress made with regard to expected resources and assets?</i> |
| <i>What is the current performance of deployed resources and assets?</i> |

Information Requirement

| |
|-----------------------------------------------------------|
| Final Interpretation |
| <i>Number and Type of appliance / equipment requested</i> |

| |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p><i>Expected time of arrival</i> <i>(Location of Dispatch, time of deployment,</i> <i>Distance to Incident, Traffic Condition)</i></p> |
| <p><i>Breakdown of expected resources</i></p> <ul style="list-style-type: none"> ○ <i>Fire Fighters, BA Wearers, Water, Foam, Pumps, etc</i> |
| <p><i>Break down of available resources</i> <i>(Location, Qty/number, Type, Duration in use, Consumption, Assigned task or job)</i> <i>Stocks & consumption of water & foam</i></p> |
| <p><i>Location and Movement of</i></p> <ul style="list-style-type: none"> ▪ <i>Fire Fighters</i> ▪ <i>Deployed and Expected Physical Resources (Appliances)</i> |

Theme: Sub goal 3.3 - Ensure accurate assessment of the operational progress (In the case of first IC to attend – Ensure on arrival risk/benefit analysis)

Decision Requirements

| |
|-----------------------------------------------------------------------------|
| Final Interpretation |
| <i>What is the progress made towards rescues/salvage?</i> |
| <i>Are there any further casualties to be rescued/salvage to be done?</i> |
| <i>What is the level of control with regard the fire and other hazards?</i> |
| <i>Rate of fire fighter deployment?</i> |

Information Requirements

| |
|------------------------------------------------------------------------------|
| Final Interpretation |
| <i>Total number of casualty/items to be salvaged when they were reported</i> |
| <i>Number of rescues/items salvaged</i> |
| <i>Number of fire fighter deployment</i> |
| <i>Profile of the temperature/ smoke/ fire over the period</i> |
| <i>Number of Fire fighter deployment over the period</i> |
| <i>Number of rescues (People/Property) over the period</i> |
| <i>Forecast of Fire/ temperature/ smoke</i> |

Appendix 4.15: Template of the Comment Sheet Used for the Validation of Decision-making and Information Requirements

| Goal Reference | Comments on Decisions | Comments on Information |
|-----------------------|------------------------------|--------------------------------|
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |

Appendix 4.16: Participant Feedback Relevant to Validation of GDI Diagram for the Goal “Maintain Strategy for/Coordination of Removal or Neutralization of Harmful Utilities/Equipment”

Appendix 4.16.1: Validation Source 1- Interviewees participated for information elicitation process

| Comments On | Feedback Reference | Interviewee 1 | Interviewee 2 | Interviewee 3 | Interviewee 4 | Interviewee 5 |
|------------------------------|--------------------|------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------|
| Information Requirements | 2.1.3 – S1.11 | Show the Area of impact (Zone) on a map | Important to know the effective area of the hazard caused by these dangerous utilities or equipments | | Information on the area of hazard impact is important | |
| | 2.1.3 – S1.12 | It is equally important to include the spread of chemicals as information need | | It will be very handy if we know where other hazards like chemicals is spreading as it may have a impact | know the location or coverage information due to chemicals or other similar hazards may also help in this situation | |
| | 2.1.3 – S1.13 | | To answer the question about on-site expert support I like to know the type of specialists, number and where can I locate them | About the specialist we may want to know how many of them available and who are they, etc. etc... | | |
| | 2.1.3 – S1.15 | Like other harmful utilities building components or structure itself may cause danger | | What about having some information on structural elements of the building it can be bad as any other hazard... | | |
| | 2.1.3 – S1.16 | Apart from real-time spread as described for other elements it will be a bonus if we have the forecasted spread of chemicals | If I can have both current and future movement of chemicals or other similar hazard, it will be very much easy to see how it affect the risks generated from these equipments or utilities | | Can you forecast how other hazards in the nature of chemical is going to affect and can the fire spread into the area of where these hazardous utilities or equipments are located | |
| Decision-making Requirements | 2.1.3 – S1.D1 | You can consider adding the question “What is the safety zone” | I will have to decide where is the safer area before I make any other plans | | Question may arise with regard to making the decision on identifying the region of impact | |
| | 2.1.3 – S1.D2 | Apart from above you may have to think of what sort of | | How it affect outside public or other premises nearby | We also have to decide the danger that can be caused by | |

| | | | | | |
|---------------|----------------------------------------------------------------------------|------------------------------------------------------------------------------------|------------------------------------------------------------|-------------------------------------------------------------------|--|
| | impact this incident may cause for different elements outside the incident | | and of course on environment. I think that is missing here | the incident on external parties and also surrounding environment | |
| 2.1.3 – S1.D3 | You missed our concerns about expert support availability | Is there any specialist available for us to get some advice this can be a question | | | |

Appendix 4.16.2: Validation Source 2 – Independent SMEs representing Nottinghamshire, Leicestershire & Derbyshire FRS

| Comments On | Feedback Reference | Interviewee 1 | Interviewee 2 | Interviewee 3 | Interviewee 4 | Interviewee 5 |
|------------------------------|--------------------|---------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------|---------------|
| Information Requirements | 2.1.3 – S2.I5 | It is crucial that we know the coverage of any hazard that can be due to any particular utility or equipment | I need to know the area from where we can deal with the hazards caused by dangerous equipments | I want to know from where we can safely stand before we do anything | | |
| | 2.1.3 – S2.I1 | Apart from the danger from things like walls and glass can we know how other hazards like chemicals are spreading in the area? | I also like to know what is the spread of other hazards such as chemicals | | | |
| | 2.1.3 – S2.I2 | Who are the experts available ,on what they are specialized | With regard to the question of experts we may want to have summary of available specialists | | | |
| | 2.1.3 – S2.I4 | Similar to the information like harmful equipment information on building structure can be also useful as this may have impact on external safety | | | What about knowhow on building material like roof and wall work. As sometimes glass wall can be as danger as other thing | |
| Decision-making Requirements | 2.1.3 – S2.I7 | | Present and future movement of chemicals and other hazards can also help us achieving this goal | On top of that if we can have the forecast of such movement it will be a bonus | | |
| | 2.1.3 – S2.D3 | We may have to quickly decide and identify the safer area to face the hazards from the dangerous utilities | I will have a question of identifying the boundary of safety generated by the hazards. | I have to decide the boundary where it can be affected by the hazardous equipment. | | |
| | 2.1.3 – S2.D2 | Not only the area you may have to find what danger this fire can cause to | How hazards going to affect external environment and | | What sort of harm incident can cause on | |

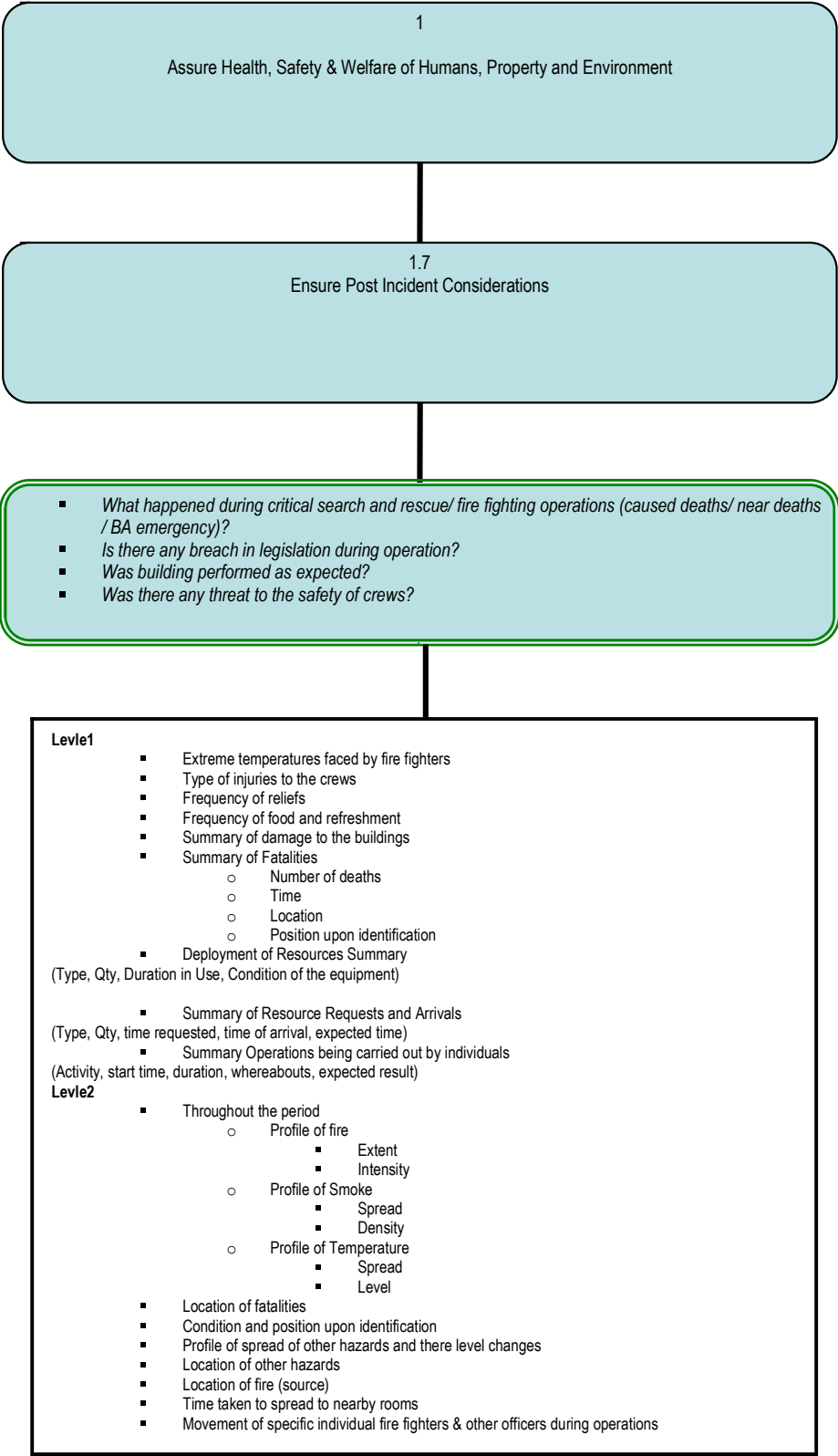
| | | | | |
|---------------|-------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------|----------------------------------------------------------------|--|
| | outside people and other elements | general public this is another question you may have to find answers | external parties and the vicinity is also important to look at | |
| 2.1.3 – S2.D1 | In large incidents We always look is there any specialist or experts from whom we can get some advice | You need to think about the amount of expert support available at the incident | | |

Appendix 4.16.3: Validation Source 3 – Command Support Teams of Leicestershire & Derbyshire FRS

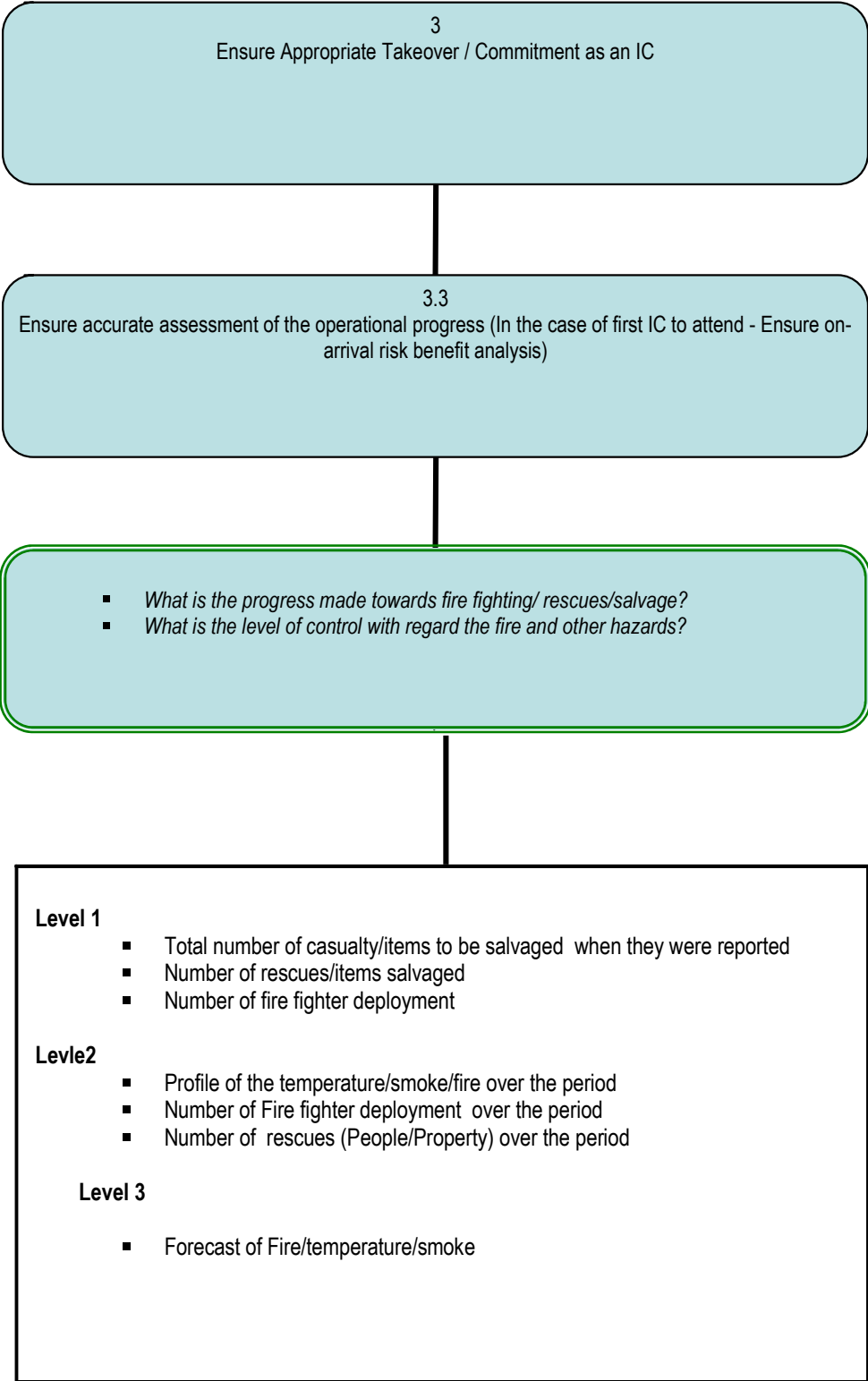
| Comments On | Leicestershire CS Team | Derbyshire CS Team |
|--------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Feedback Reference | Leicestershire CS Team | Derbyshire CS Team |
| Information Requirements | 2.1.3 – S3.I3 Better if we can provide the information on hazard impact zone due to any harmful utility or equipment | It is very important to have accurate information on the area where this hazard going to affect |
| | 2.1.3 – S3.I2 Apart from the information on utilities and equipments, how others hazards are spreading nearby is also important, especially chemicals, gases and similar other hazards that can have impact on these dangerous equipments. | |
| | 2.1.3 – S3.I1 For us to answer questions of expert support we need some basic information about the available experts | Summary of available expertise may be handy. For example type and number of experts and also where are they now. |
| | 2.1.3 – S3.I5 Apart from possible harmful material or utilities structural material of the building like glass may cause some harm to the surrounding vicinity. So better to have such information as well ... | In order to decide the impact on the external environment and people it may be handy to have information like the material which this building is made of. |
| | 2.1.3 – S3.D4 IC's may have to decide what is the zone of impact due to any hazard caused by these dangerous utilities and equipments | We may have to provide the information so that officer in charge can make the decision on deciding the safety cordons. |
| Decision Requirements | 2.1.3 – S3.D2 ICs often want to know whether they can get any external expert support at the incident ground | Also IC may want to know what sort of danger this incident may cause on external environment and the public |
| | 2.1.3 – S3.D1 ICs often want to know whether they can get any external expert support at the incident ground | We may asked by the ICs to check the availability of incident support at the incident ground |

Appendix 4.17: A Sample of Validated GDI Diagrams

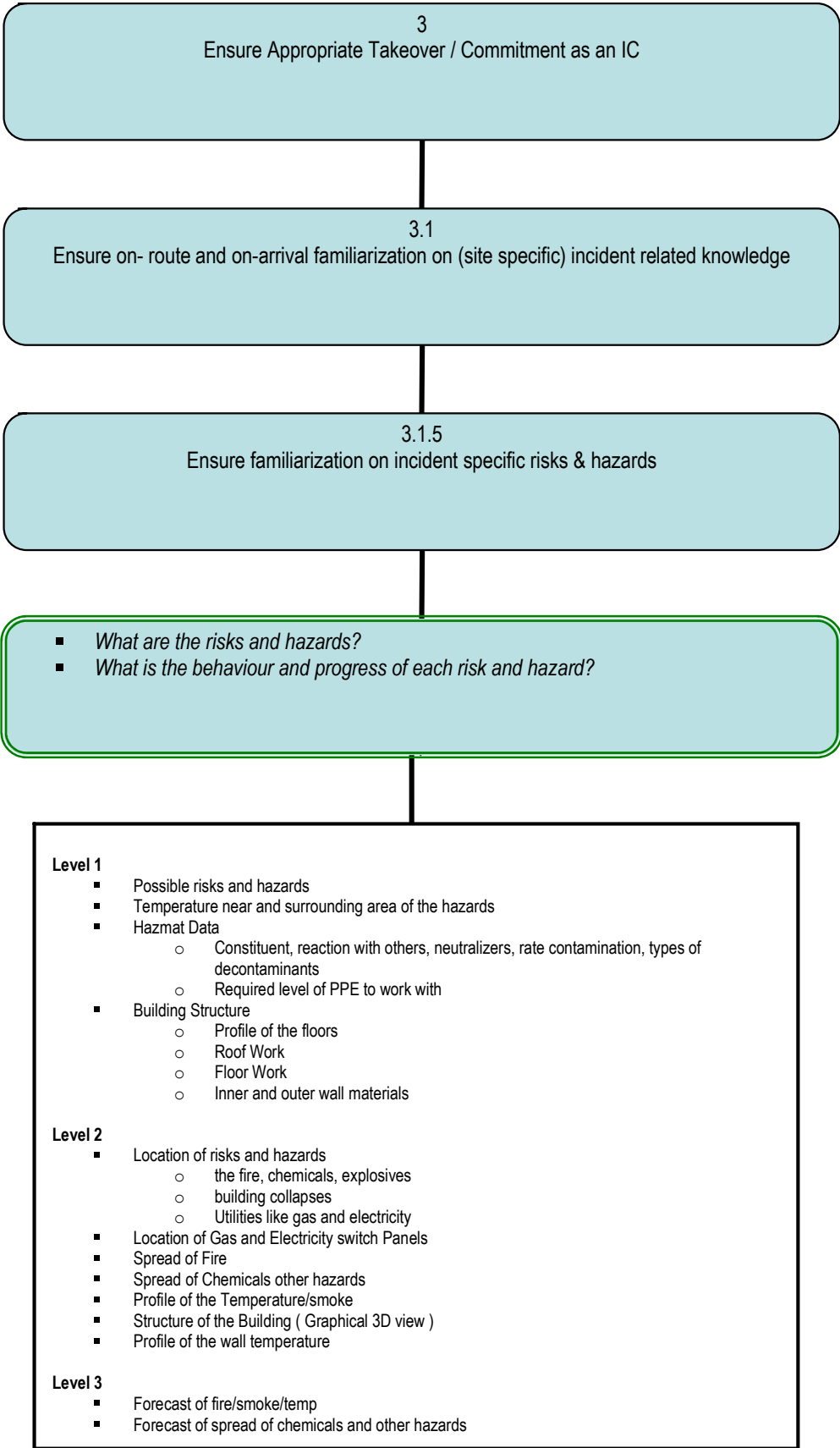
GDI Diagram for a Secondary Goal of an IC



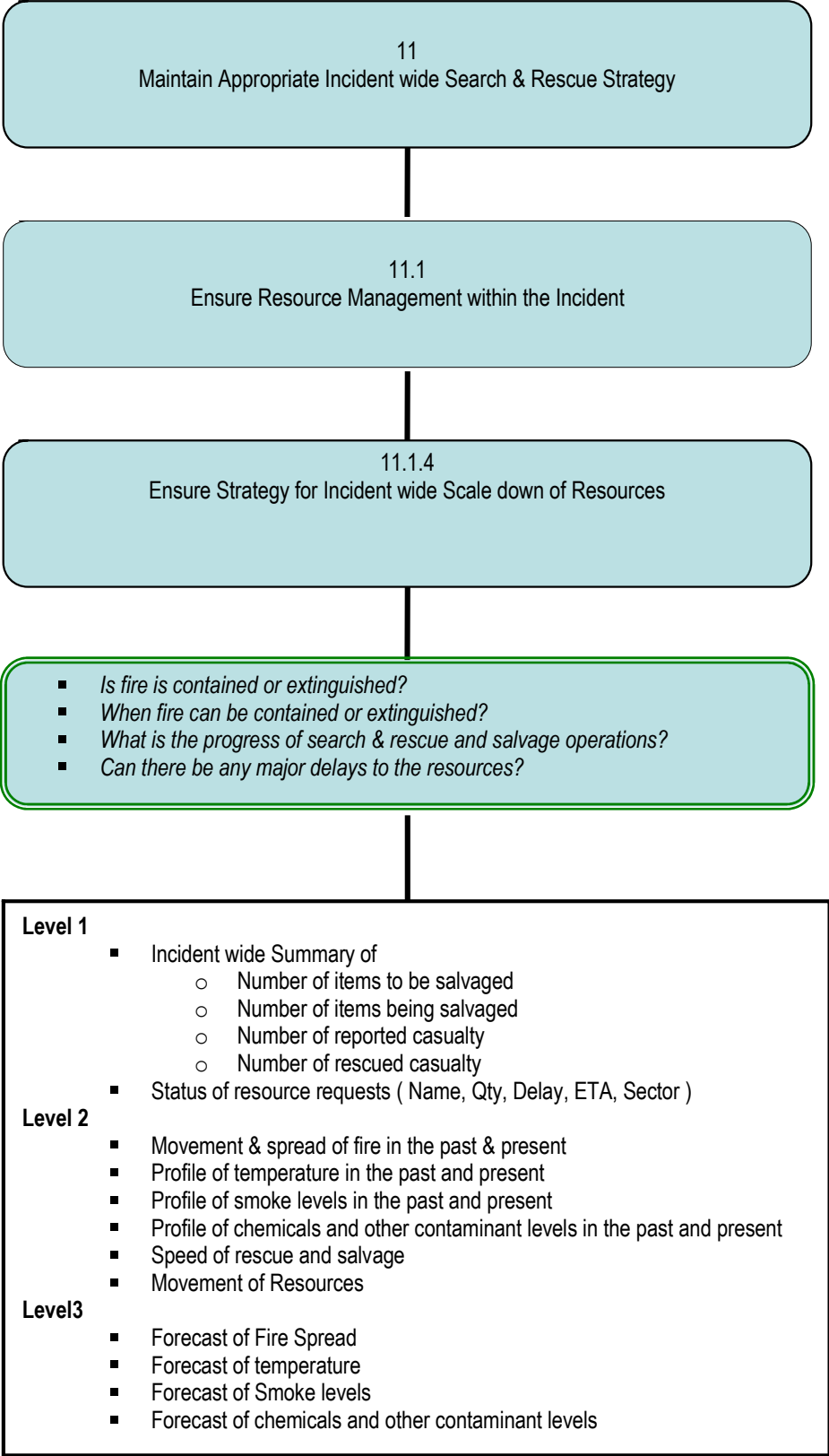
GDI Diagram for a Tertiary Goal of an IC



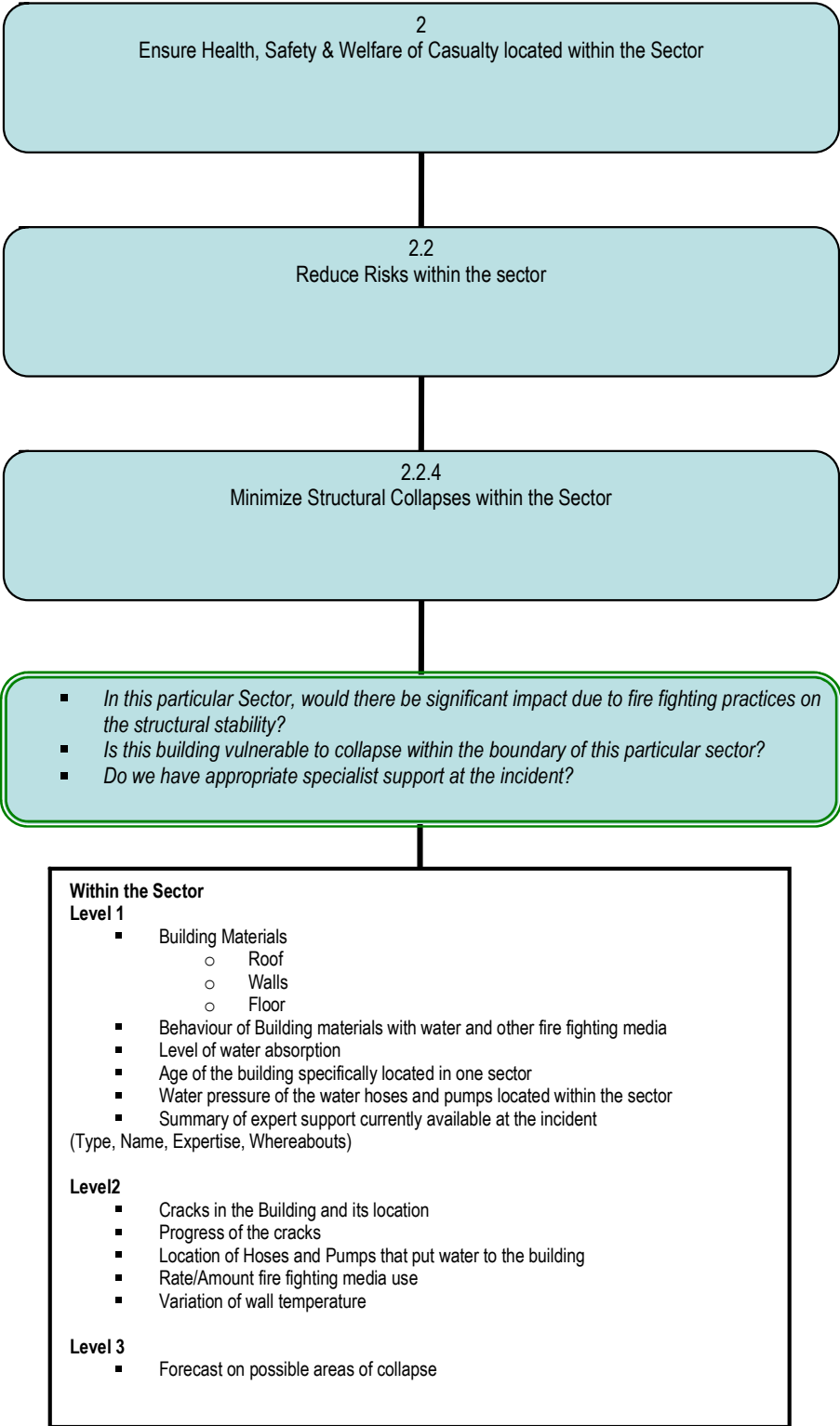
GDI Diagram for a Tertiary Goal of an IC



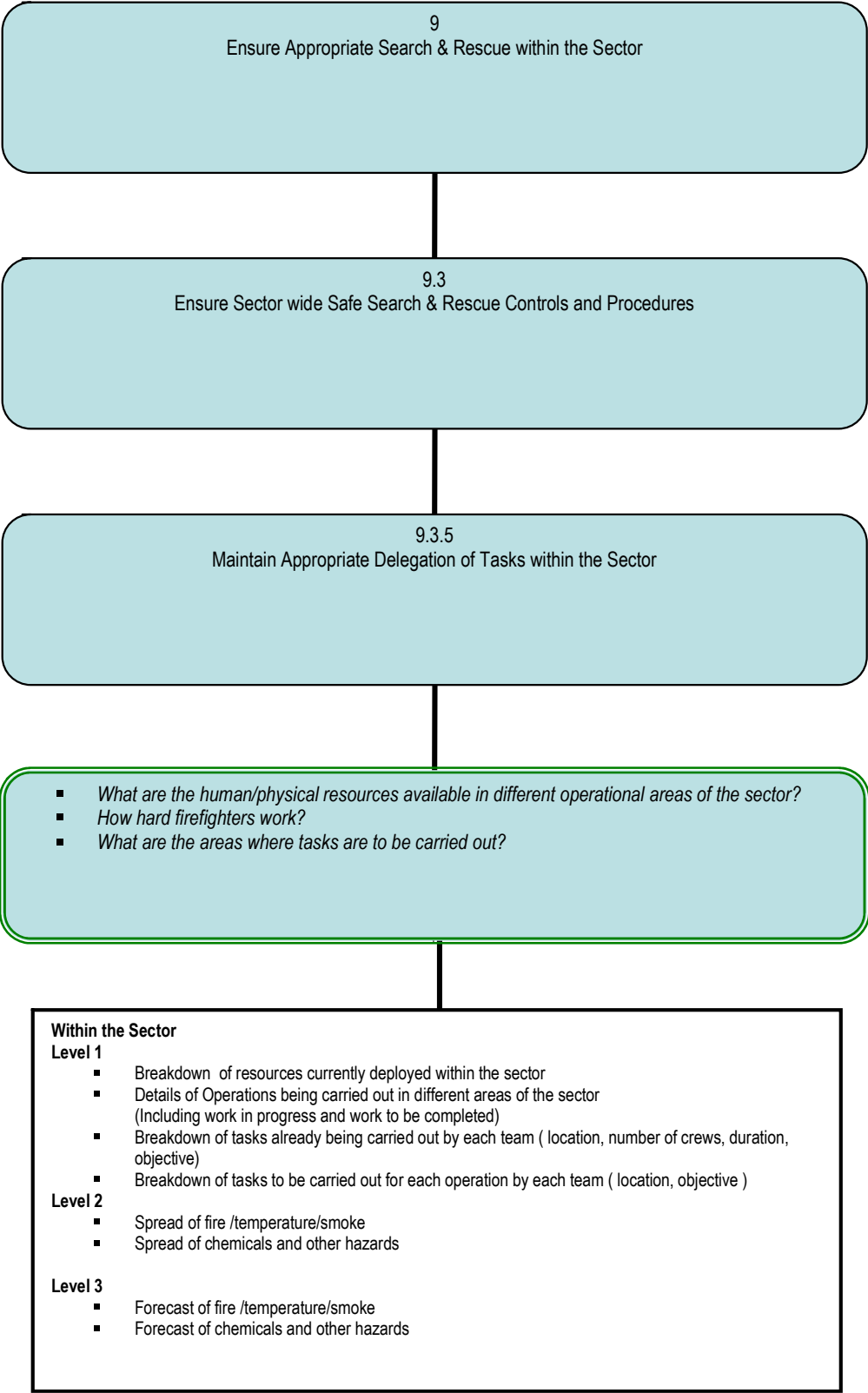
GDI Diagram for a Tertiary Goal of an IC



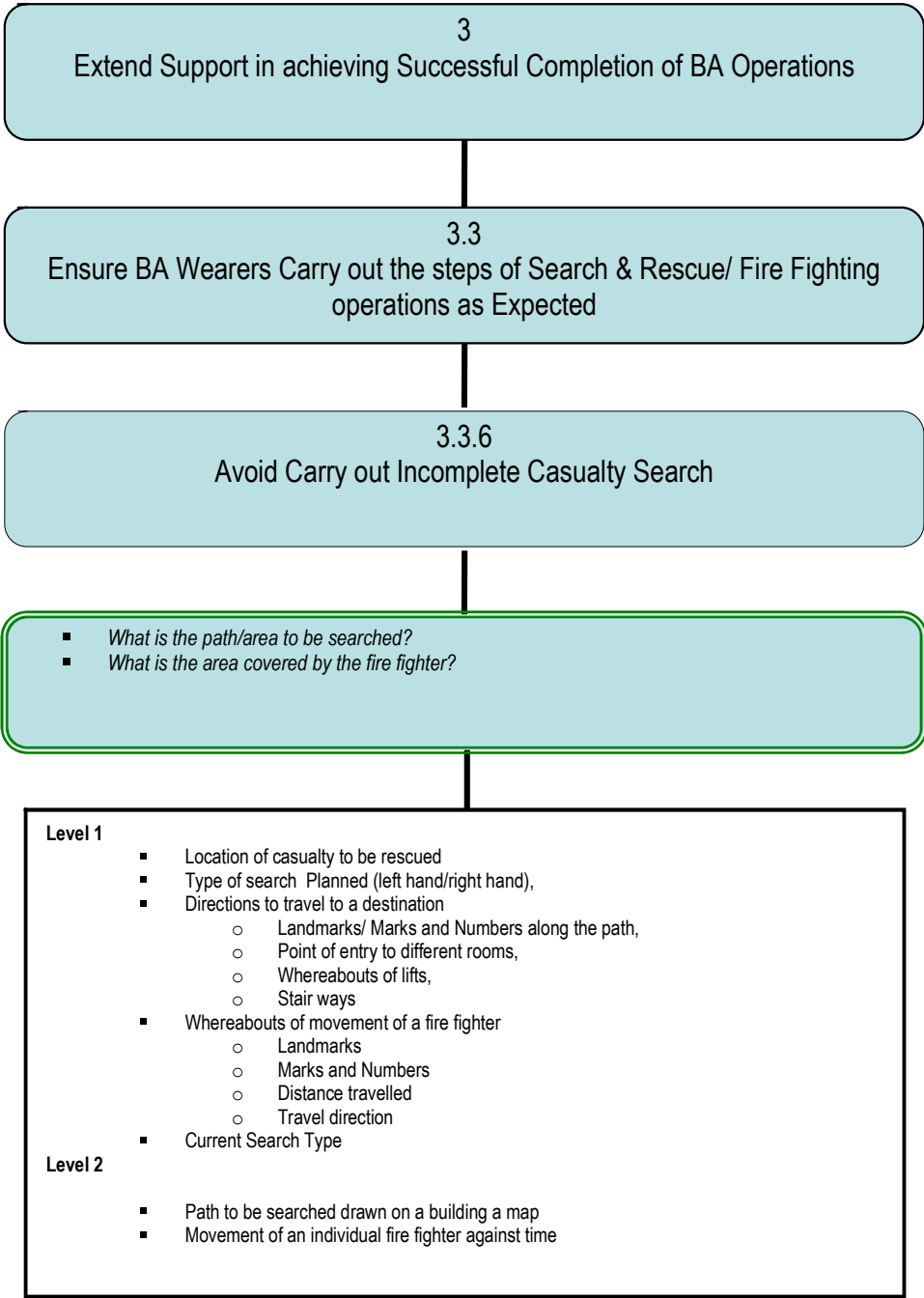
GDI Diagram for a Tertiary Goal of a SC



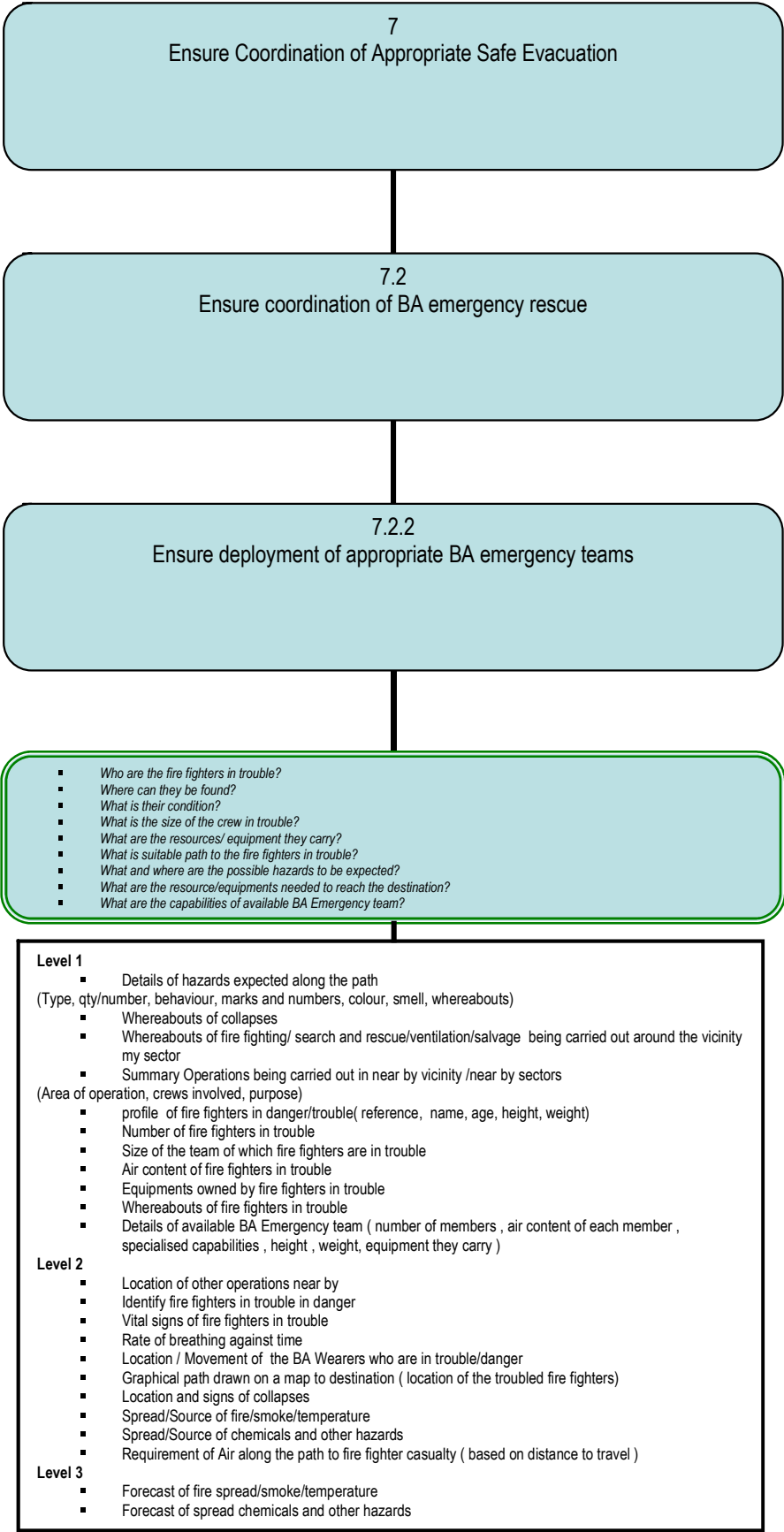
GDI Diagram for a Tertiary Goal of a SC



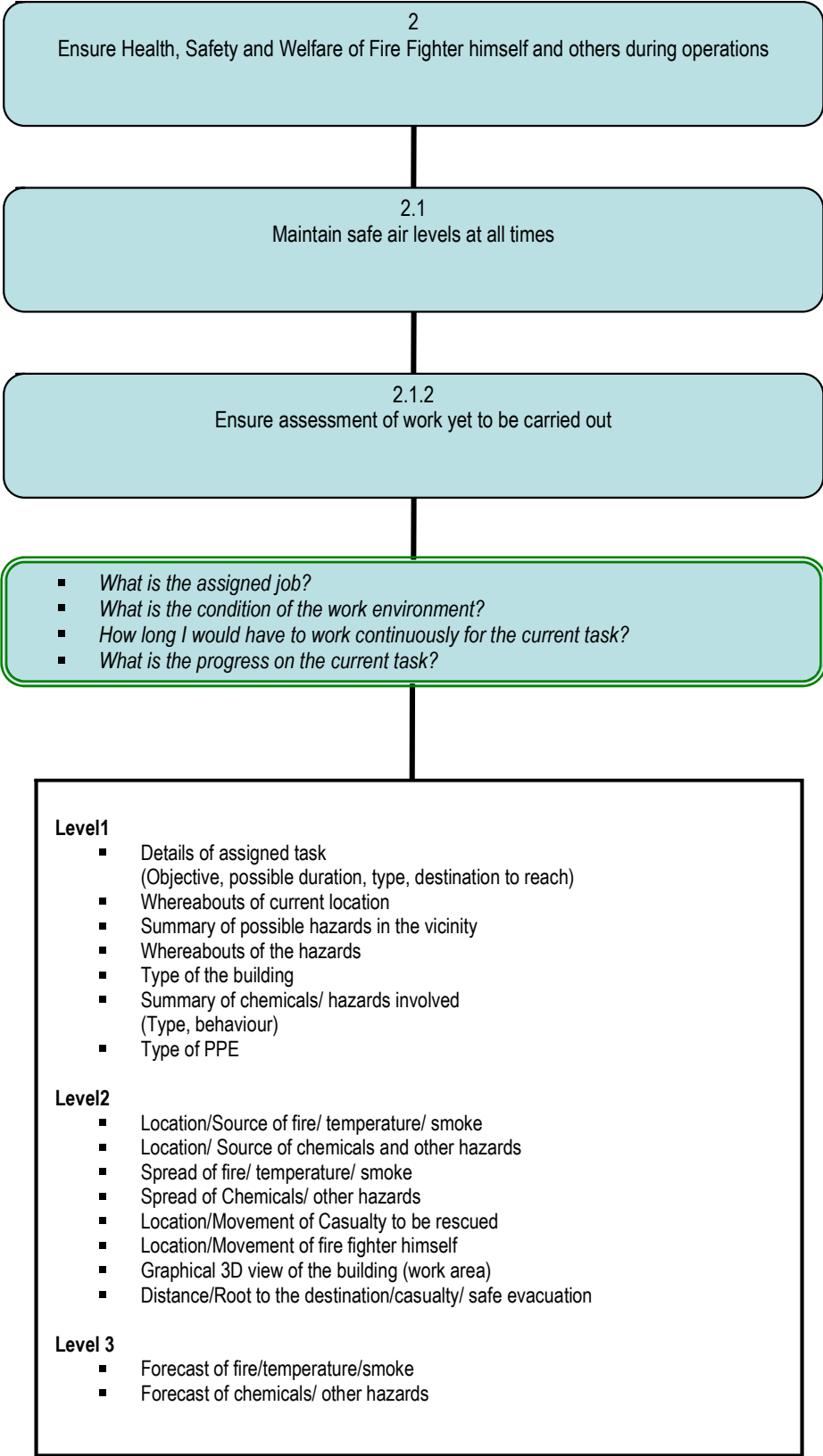
GDI Diagram for a Tertiary Goal of a BAECO



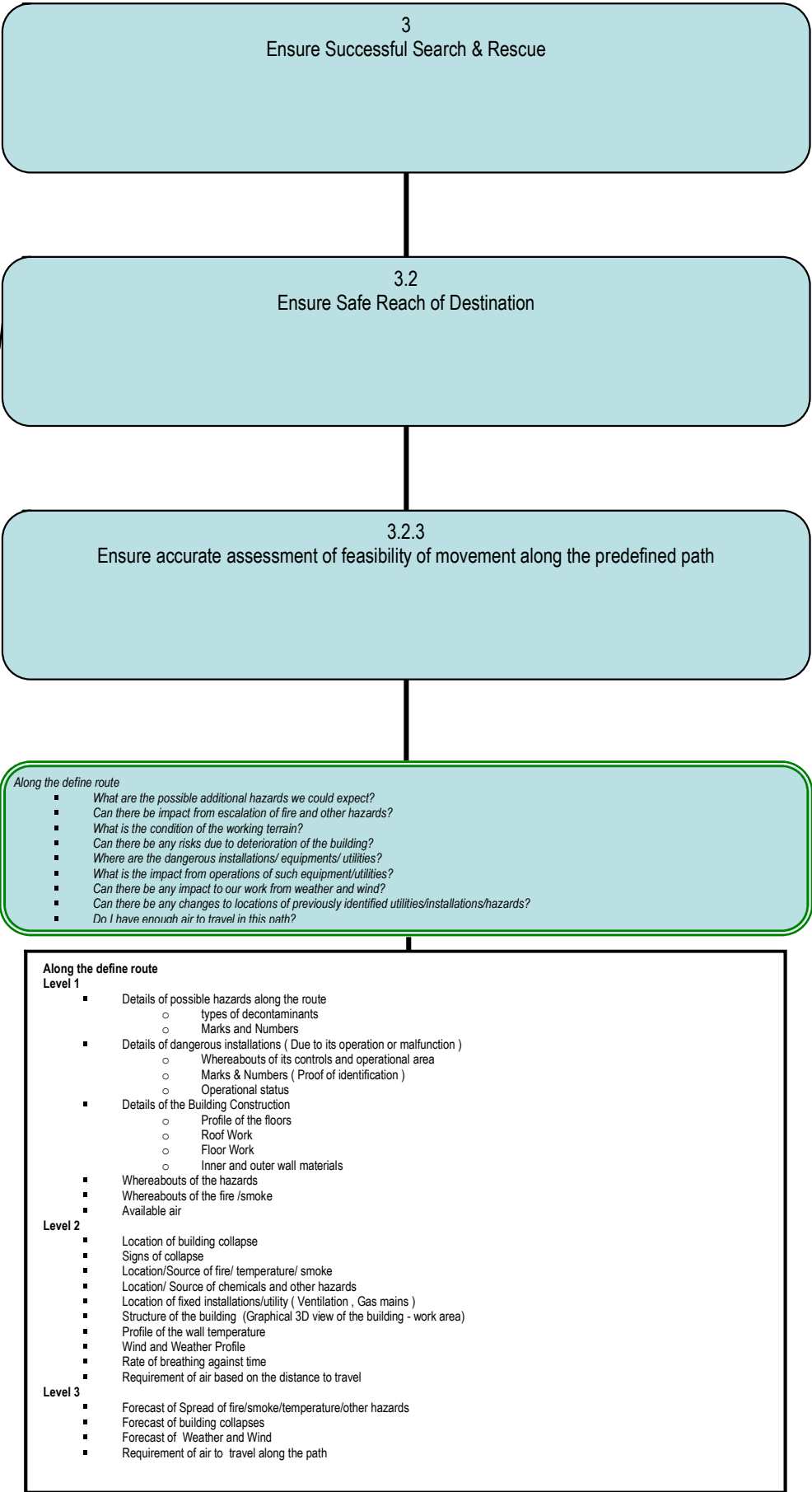
GDI Diagram for a Tertiary Goal of a BAECO



GDI Diagram for a Tertiary Goal of a BA Wearer



GDI Diagram for a Tertiary Goal of a BA Wearer



Appendix 5.1: Selection of Catalogued Field Notes Relevant for Chapter 5

Catalogued Field Note Ref. 4.4 based on the Observations made during BA Wearer Training on 13th July 2008 (Day 1)



Photo 4.4: Two Way Radio considered as an essential part of the BA Wearer Kit

Fire fighters have to routinely check and maintain their two-way radio device in working order with charged batteries as it is the only way of communicate with the outside when they are doing the operations.

Catalogued Field Note Ref. 4.8 based on the Observations made during BA Wearer Training on 16th July 2008 (Day 2)



Photo 4.8: Thick gloves make it difficult to touch and feel

Very thick safety gloves make it difficult to handle equipment and reduce the feel of the external environment.

Catalogued Field Note Ref. 4.14 based on the Observations made during BA Wearer Training on 17th July 2008 (Day 3)

Instructors were banging to a metal sheet with a stick to make it lot of noise inside the training unit. **Movie Clip 4.14-MOV0293** clearly shows the loud noises created by the instructors to obstruct the communication between the fire fighters themselves and between the fire fighters and the outside. This clearly made fire fighter communication difficult as they find it very difficult to hear their own voices.

Catalogued Field Note Ref. 4.15 based on the Observations made during BA Wearer Training on 17th (Day 3) July 2008



Photo 4.15: Simulating the difficulty of visual ability during

Fire fighters were blind folded to simulate the visual conditions expected around the epicentre of the fire ground. Therefore, they should be ready to use their hands and legs effectively with limited visual capability to find their way.

Catalogued Field Note Ref. 4.19 based on the Observations made during BA Wearer Training on 17th (Day 3) July 2008



Photo 4.19 (1): BA Wearer Trainees doing a Left Hand Search.



Photo 4.19 (2): Fire Fighters Carry out Search operations with the Use of Guidelines

(Adopted from Fire Service Technical Bulletin 1/1997 BA Command & Control Procedure)

BA Wearers always carried out their movements based on either left hand or right hand search by using the walls of the building as their main reference for navigation. However, when the search area got bigger and open they use the support of the “guidelines.” Guideline is a manually laid rope. However, it is observed that when actual guidelines are not in operation, fire fighters always use their water hose as the evacuation guidance. They found it really difficult to use both guideline and water hose when they were asked to evacuate with a casualty. Sometimes both members of a two member fire fighting team have to carry two casualties. In this particular exercise it was observed that when a team of two fire fighters were asked to evacuate with a child and a male casualty, they found it difficult to avoid them getting tangled with their water hose. Other difficulty was to lay the guidelines without getting tangle with furniture and other equipment on the floor.

Catalogued Field Note Ref. 4.25 based on the Observations made during BA Wearer Training on 21st (Day 6) July 2008.

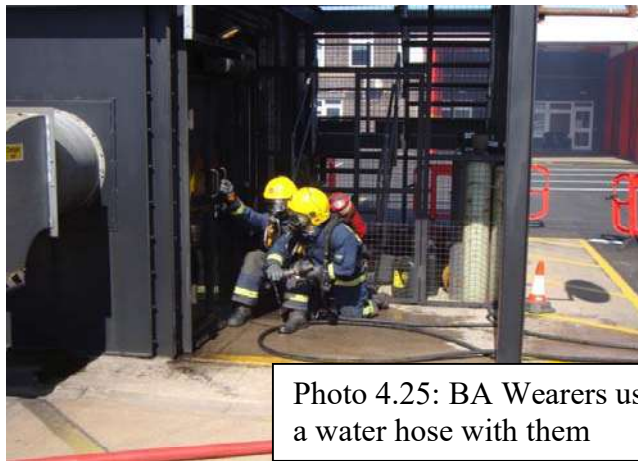


Photo 4.25: BA Wearers usually carry a water hose with them

BA Wearers usually carry a water hose in to the area where they fight fire or rescue casualty.

Catalogued Field Note Ref. 4.26 based on the Observations made during BA Wearer Training on 21st (Day 6) July 2008



Photo 4.26(1): BA Wearers carry out door procedure



Photo 4.26(2): BA Wearers carry out door procedure



Photo 4.26(3): BA Wearers carry out door procedure

As shown in the above photographs, firefighters strictly followed the door procedure before entering into a compartmentalized area considered to be filled with smoke and having fire with very high temperature. In this exercise, they first splash the door with water followed by touching the door to feel the temperature from top to bottom of the door. Also they observed how water evaporates from the door wall. When queried the importance of such procedure, one of the most senior BA Trainers at the Leicestershire fire and rescue described the following (**Voice File 4.26(1)**).

As you have seen, door procedure is one of the crucial exercises every BA team must follow before entering the compartments. But putting water and observing its evaporation and touching the door wall BA wearers try to understand what is going on behind that door, especially the temperature variation of that room; from top of the ceiling to the floor. Further they observe smoke that comes out from the door, especially from where it is coming out and the colour. With such observations BA Wearers try to decide whether it is safe to enter to that particular room and provide signs of possible flashover or backdraught. Importantly, this type of information is equally useful for the officer in charge of fire fighting as it will support him in the process of deploying fire fighters into the hazard areas. These information can be life saving, therefore if one can provide better information from the inside of the building it definitely can improve our operations

Catalogued Field Note Ref. 4.29 based on the Observations made during BA Wearer Training on 21st (Day 6) July 2008.

Most of the trainees participated for the BA simulation exercise with the actual fire conditions explained the enormous challenge they face due to both visual and hearing difficulties.

Voice File 4.29(1)-Trainee 2341: ... Yeah... You must be inside with us....you can't barely see what is going on....I think it is due to the smoke...And very difficult to hear... better to use the signs than words.....Only what you can here is the roar of the fire....

Voice File 4.29(1)- Trainee 2342: ... It was very dark inside.... obviously you can't expect lights to be on in a compartment during fire.... On top of that due to the sound of the blaze, I didn't hear a thing.... what (Name X) said to me.... Also it is very difficult to here from the radio.....

Voice File 4.29(2) – BA Trainer:You can clearly see ..what I told you earlier is true... as most of the trainees just mentioned it is really really difficult to see what is going on around when you are getting closer and closer to the incident area. Mainly due to the smoke.... also as I said earlierit is very difficult to communicate as you can't hear most of the things because of the very high noise levels..... so virtually they become disable

Catalogued Field Note Ref. 1.7 based on the Observations made during the Fire Simulation Exercise at Rolls Royce Nuclear, Derbyshire on 13th July 2007

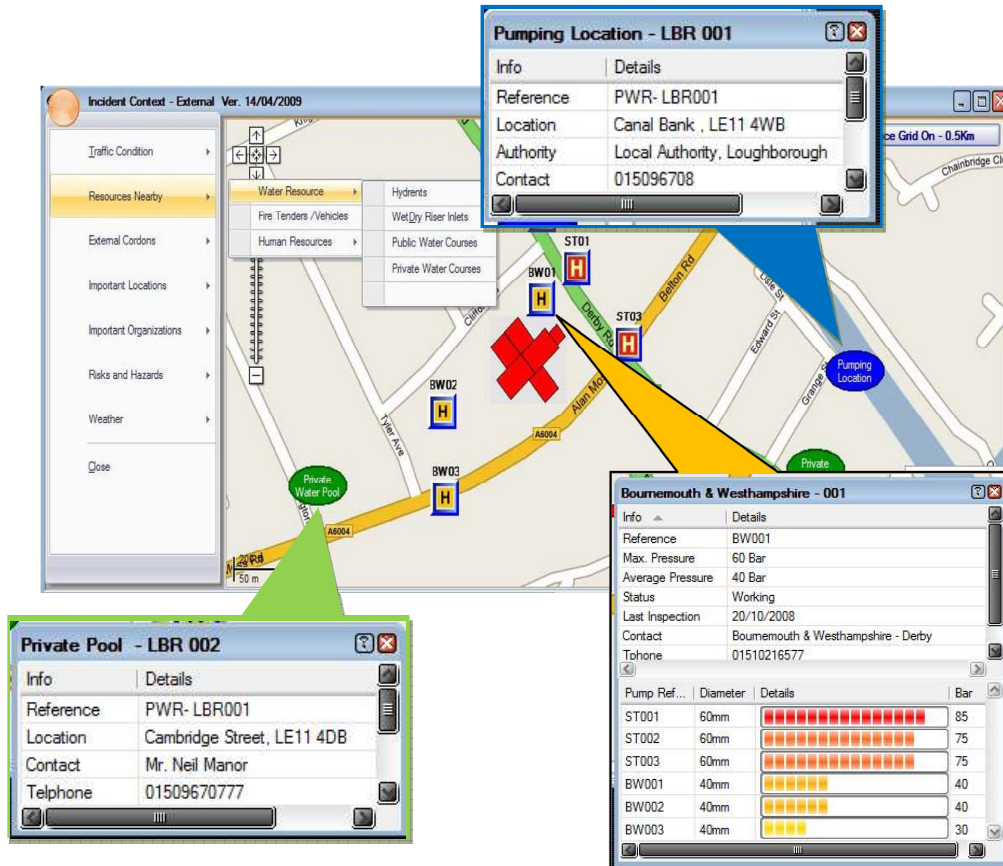


Photo 1.7(Rolls Royce): BA Wearers with Personal Guideline

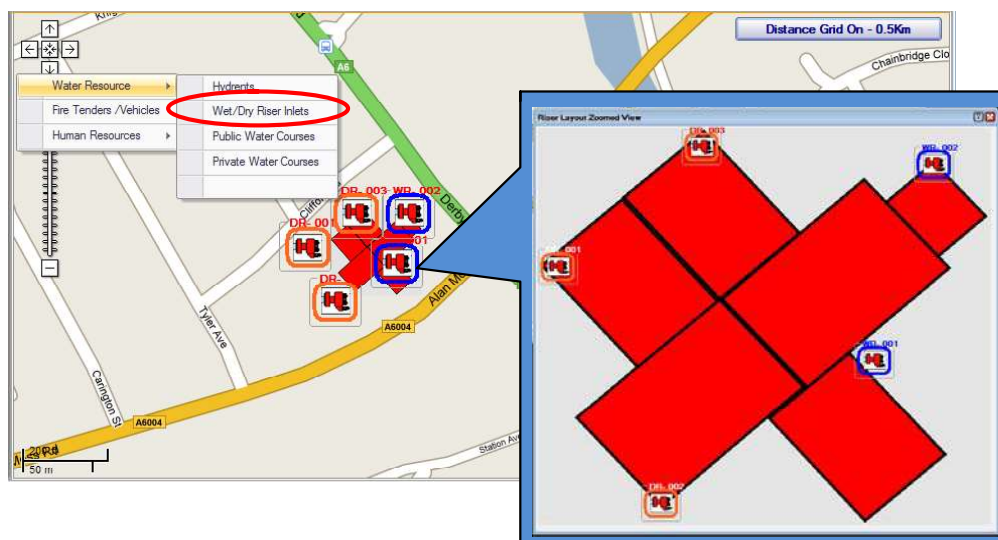
It is observed that with the assumption of having smoked filled environment all the fire fighters involved with BA operations are physically connected via a rope called “personal guideline.” Almost all the fire fighters involved in this exercise appreciate its ability to increase the safety of an individual fire fighter as it forced to fire fighters to work as a team. However, they explain how this particular procedure can cause significant restriction to the freedom of movement of an individual fire fighter.

Appendix 5.2: Some of the Useful Human Computer Interfaces Proposed

Interface Displaying Nearby Water Resources (Figure A5.2.1)

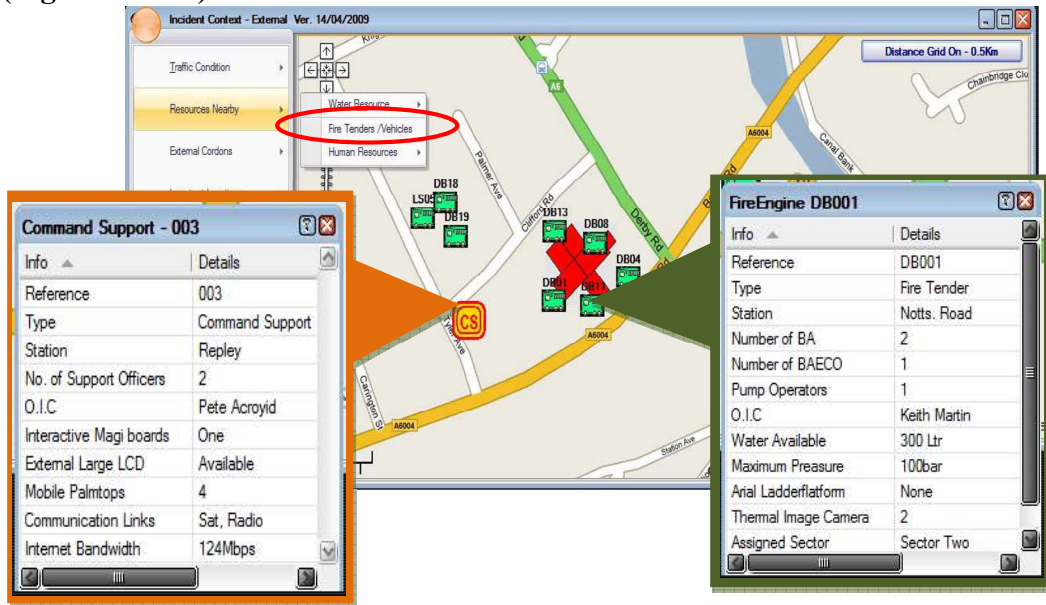


Interface Displaying Riser Inlet Locations (Figure A5.2.2)

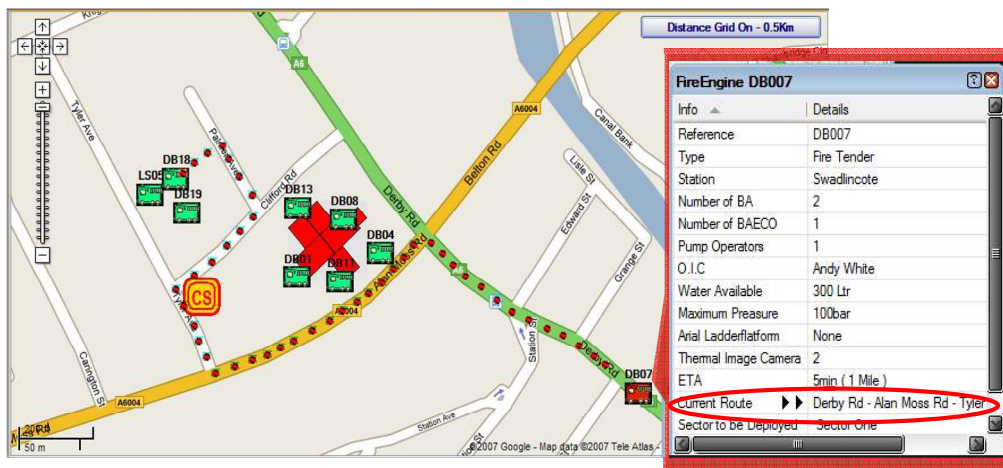


Interface Displaying Fire Tender/Vehicles related Information

(Figure A5.2.3)

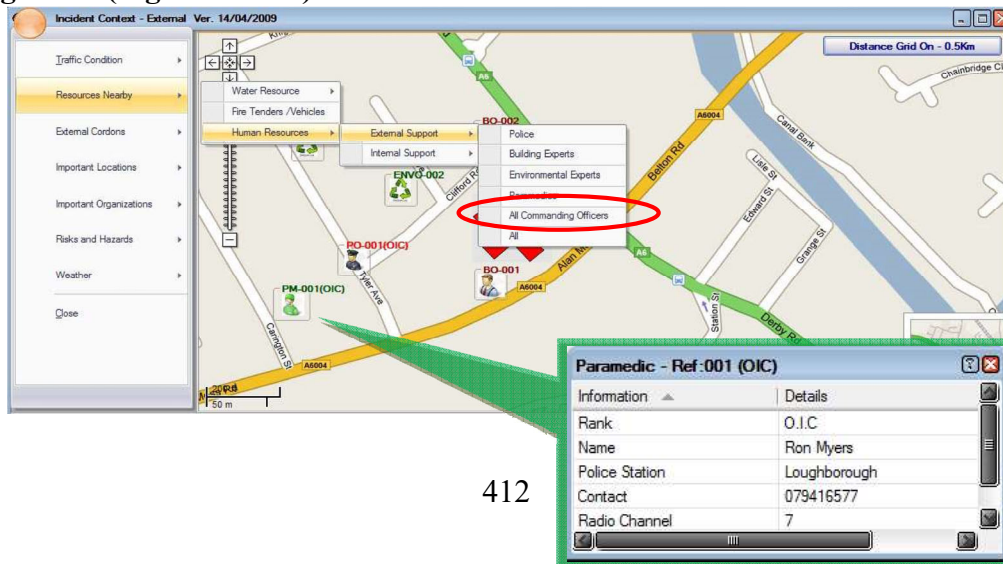


Interface Displaying On Route Fire Tender/Vehicles (Figure A5.2.4)

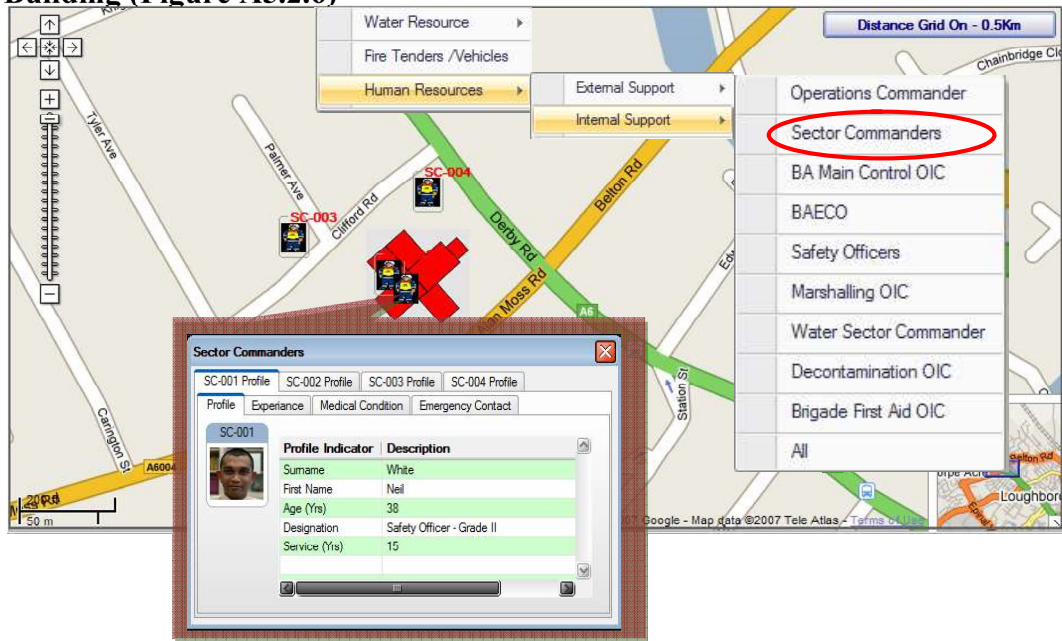


Interface Displaying Human Resource Support Received from External Agencies (Figure A5.2.5)

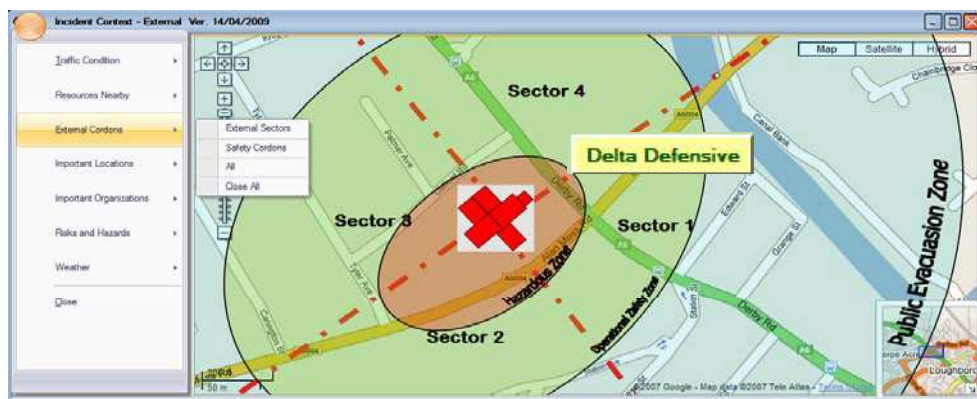
(Figure A5.2.5)



Interface Displaying Sector Commanders Deployed Outside the Incident Building (Figure A5.2.6)



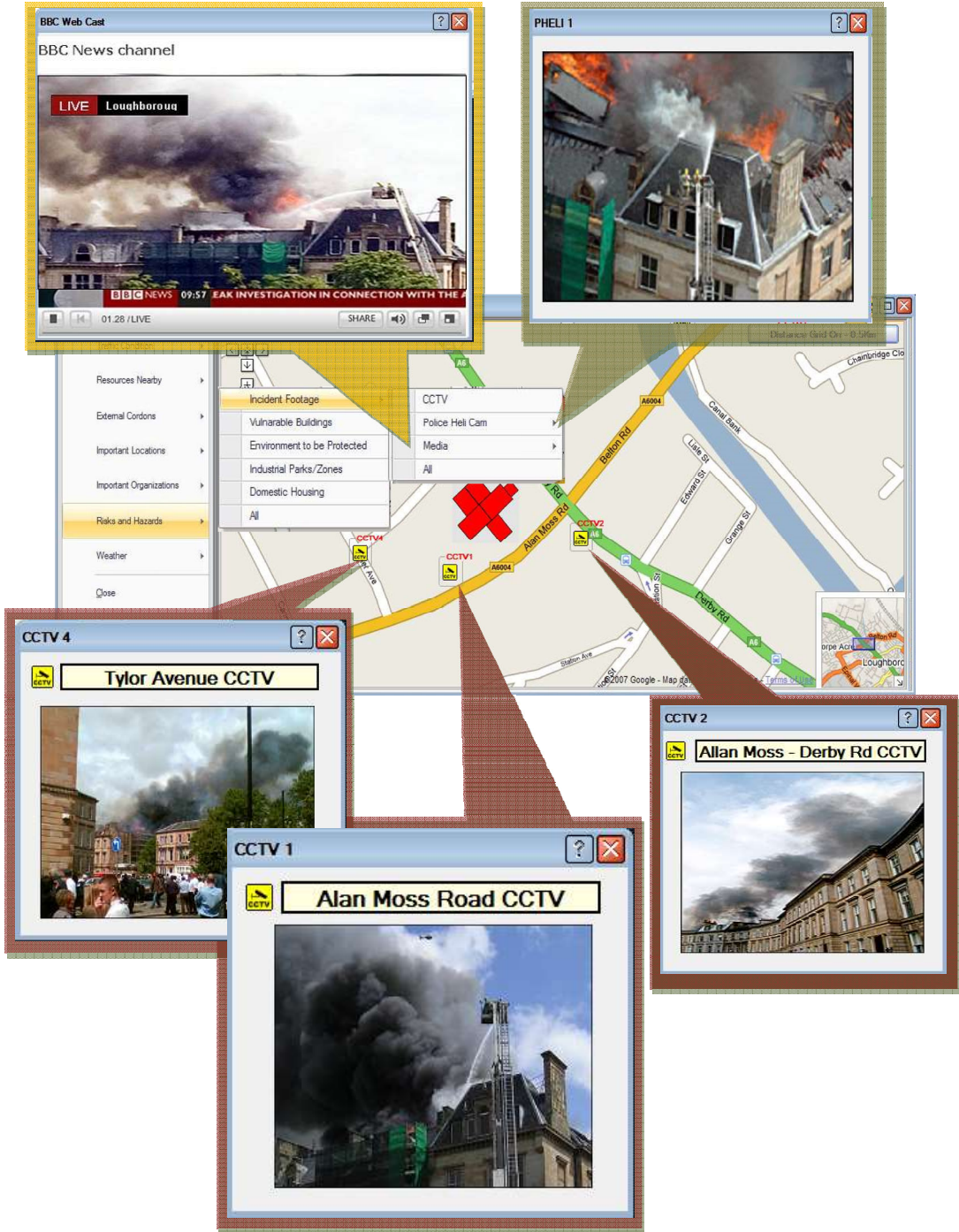
Interface Displaying External Sectors, Cordons and Tactical Modes (Figure A5.2.7)



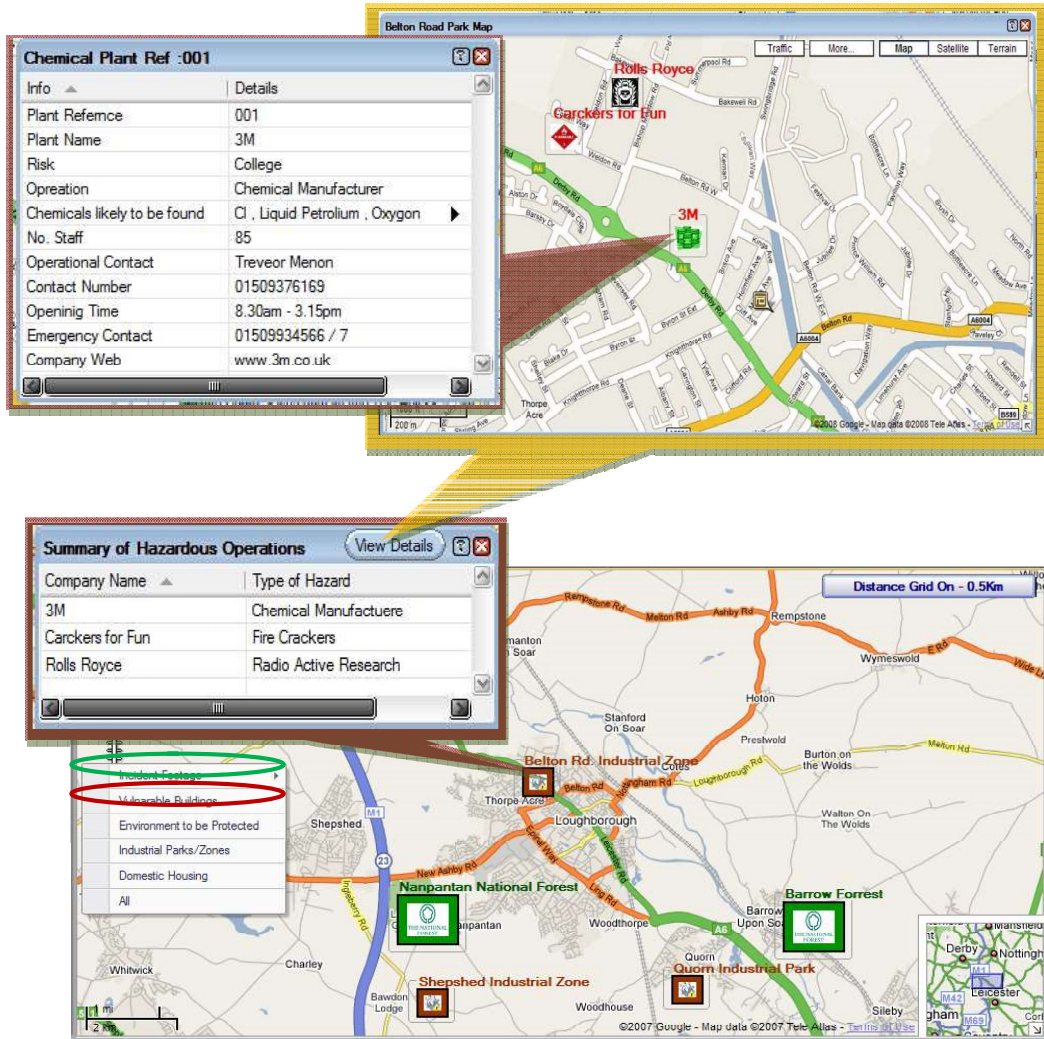
Interface Displaying Domestic Housing/Population Density (Figure A5.2.8)



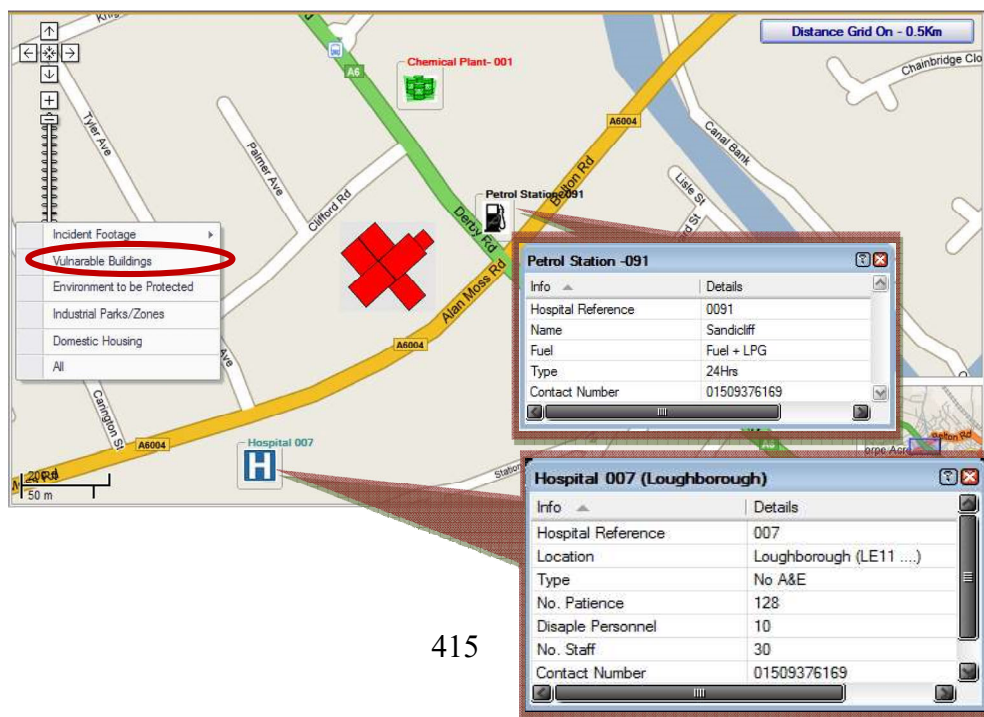
Interface Displaying 360 Incident Footage (Figure A5.2.9)



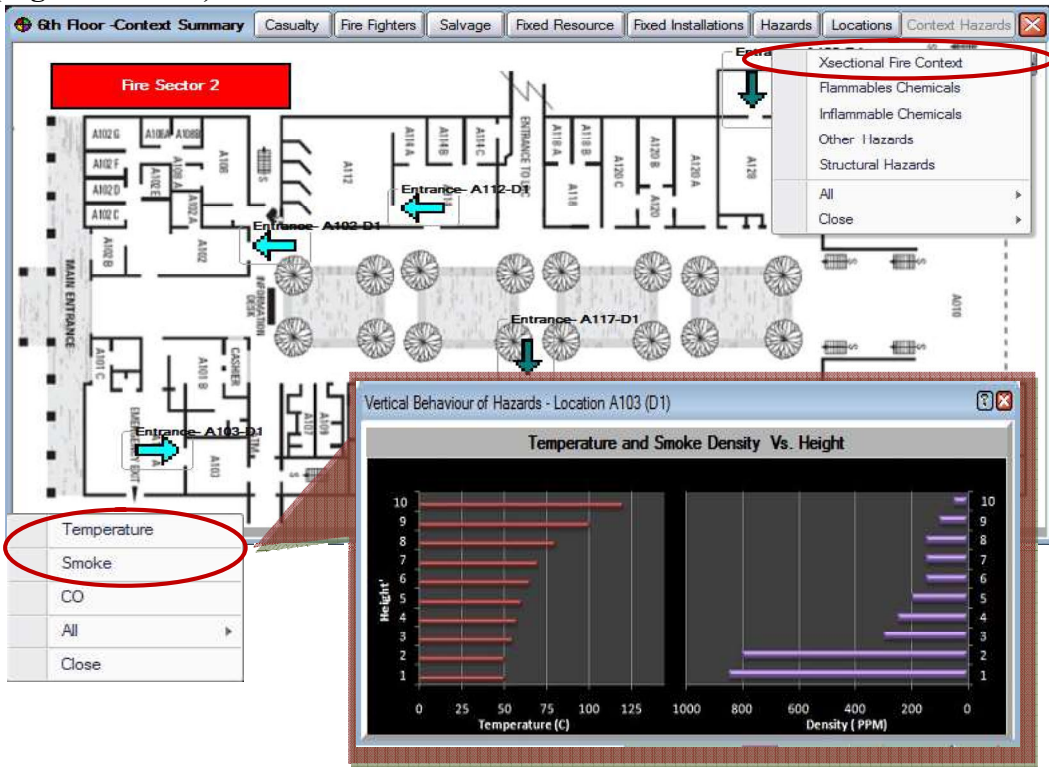
Interface Displaying Industrial Zones and Environment to be Protected (Figure A5.2.10)



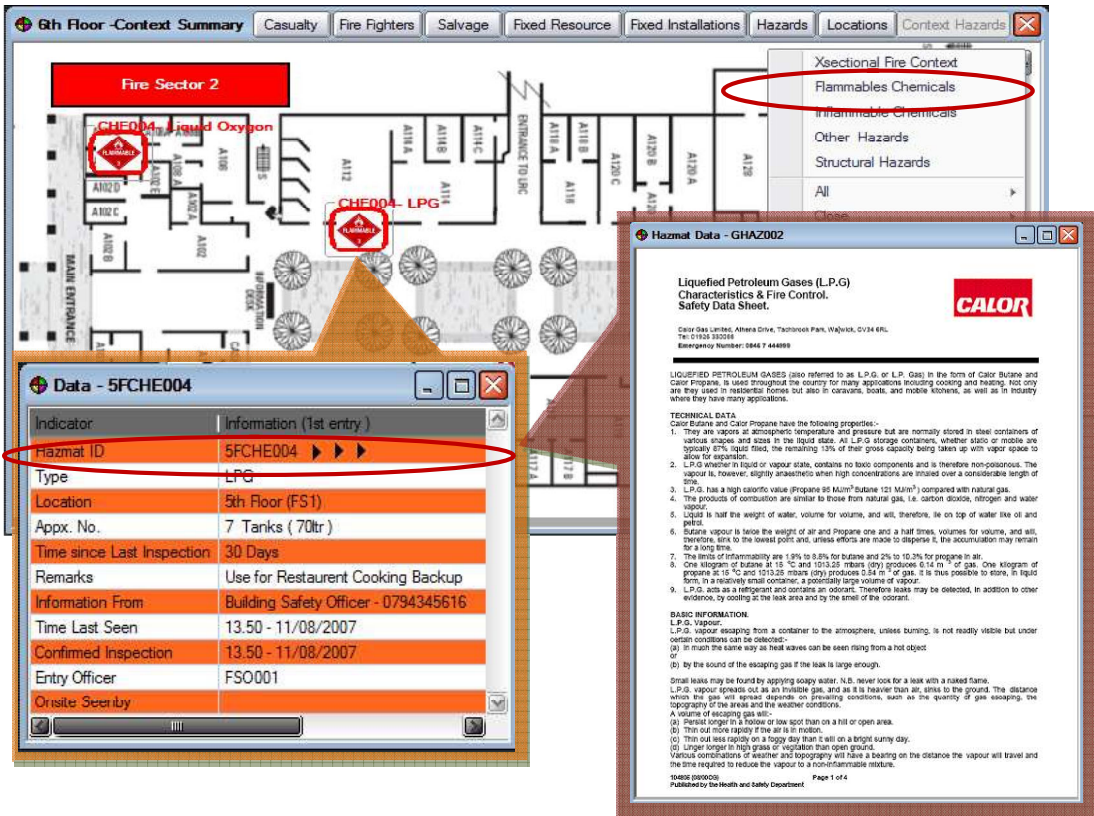
Interface Displaying Nearby Vulnerable Buildings (Figure A5.2.11)



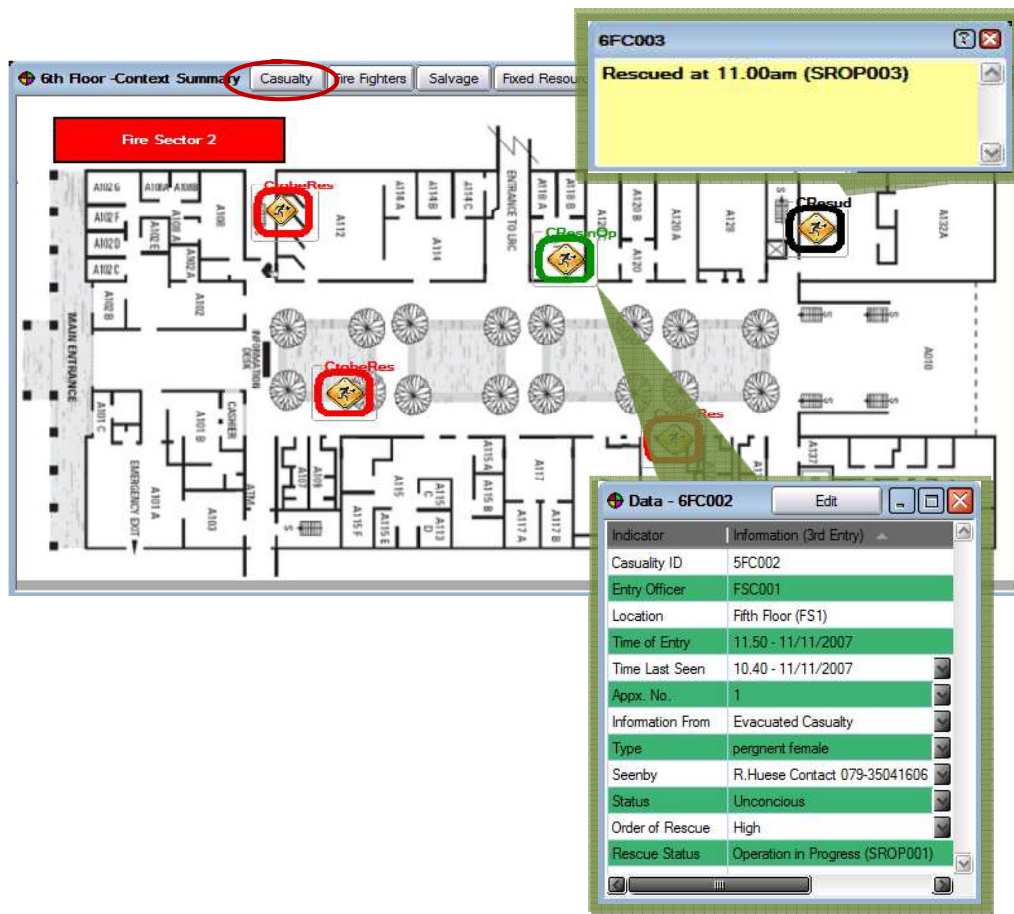
Interface Displaying Vertical Behaviour of Temperature and Smoke Density (Figure A5.2.12)



Interface Displaying Location and Hazmat Data of Flammable Chemicals (Figure A5.2.13)



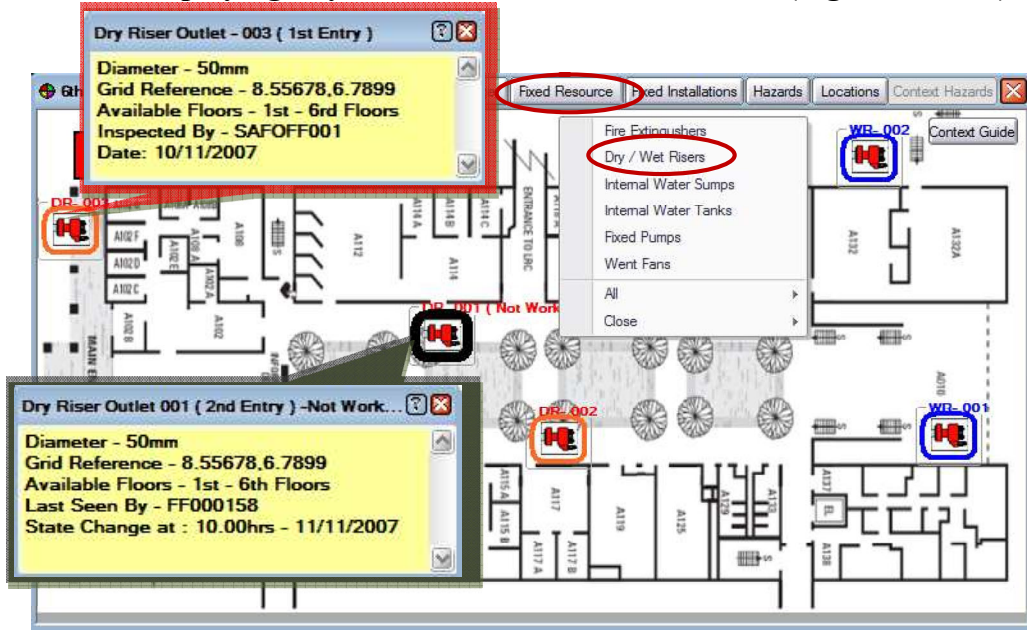
Interface Displaying Casualty Related Information (Figure A5.2.14)



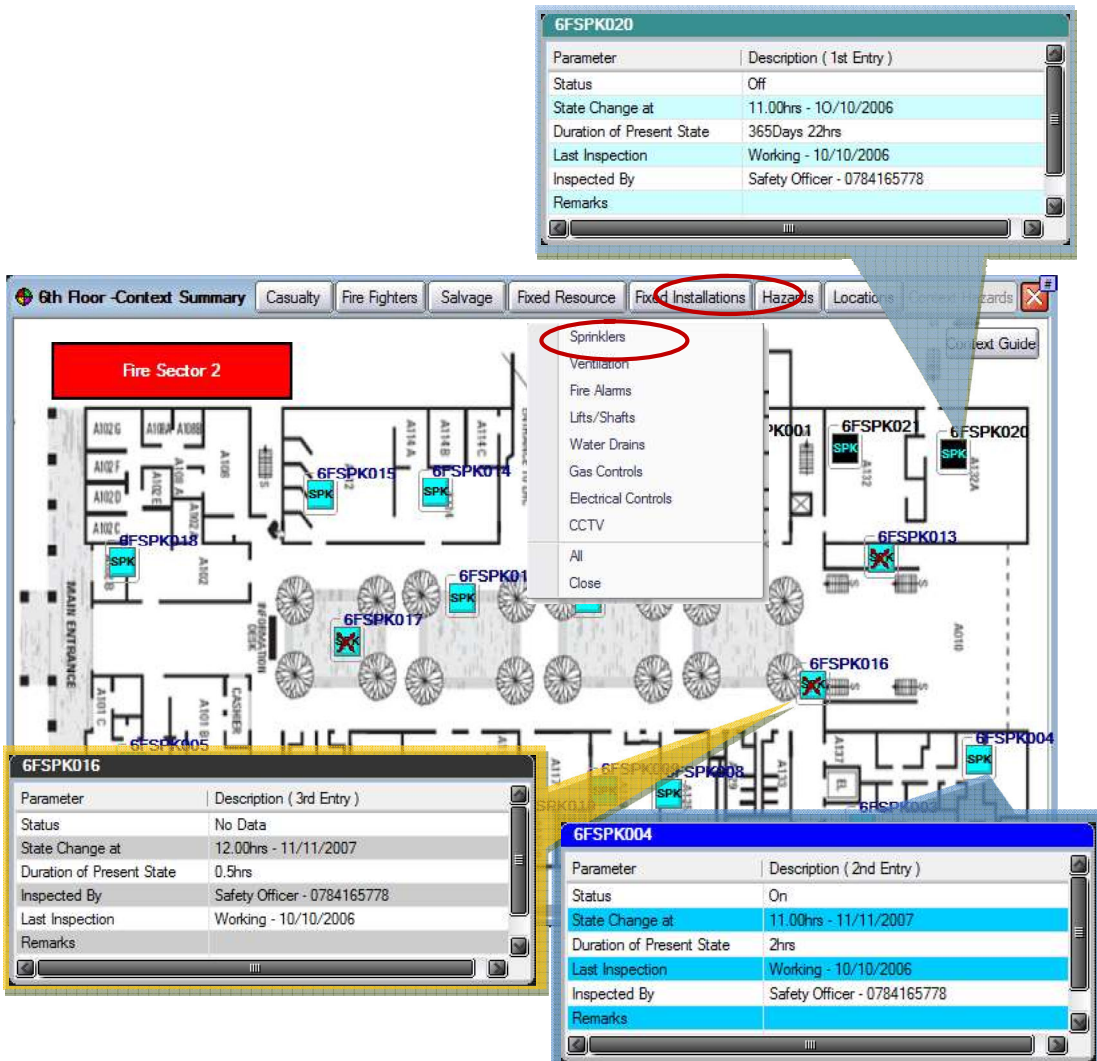
Interface Displaying Fire Fighter Location and Movement (Figure A5.2.15)



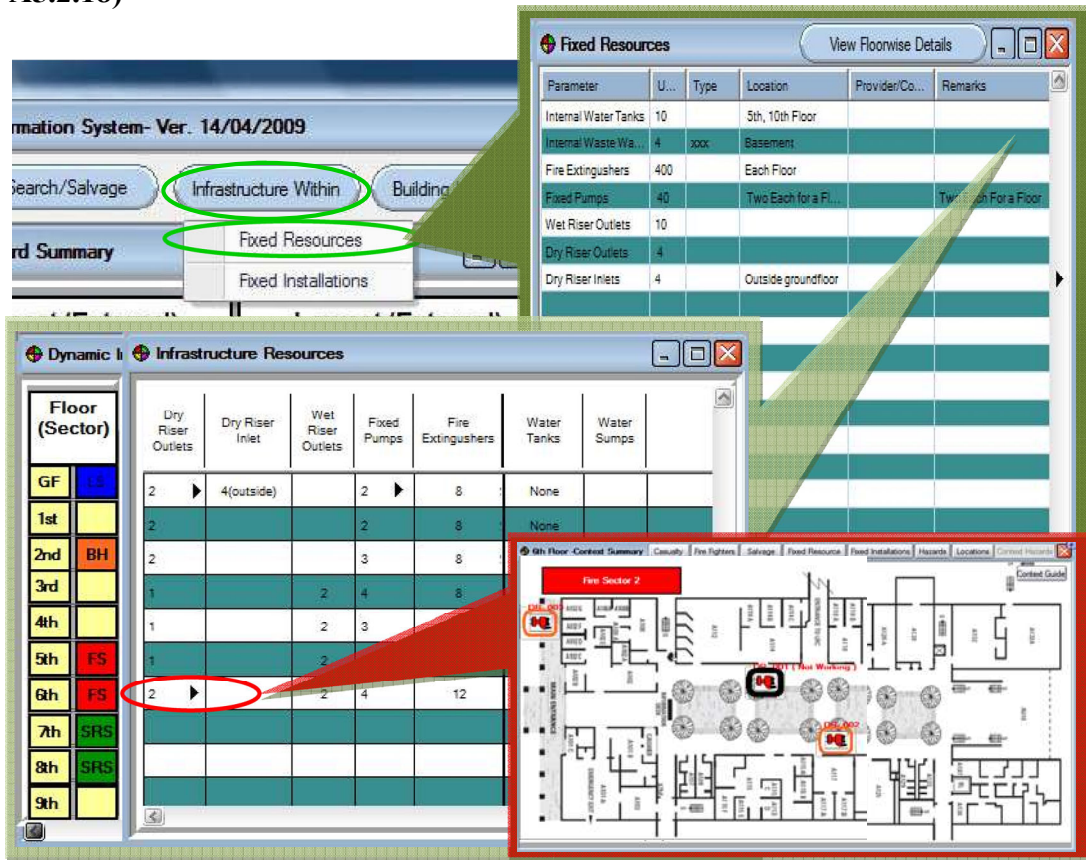
Interface Displaying Dry/Wet Riser Related Information (Figure A5.2.16)



Interface Displaying Sprinkler Related Information (Figure A5.2.17)

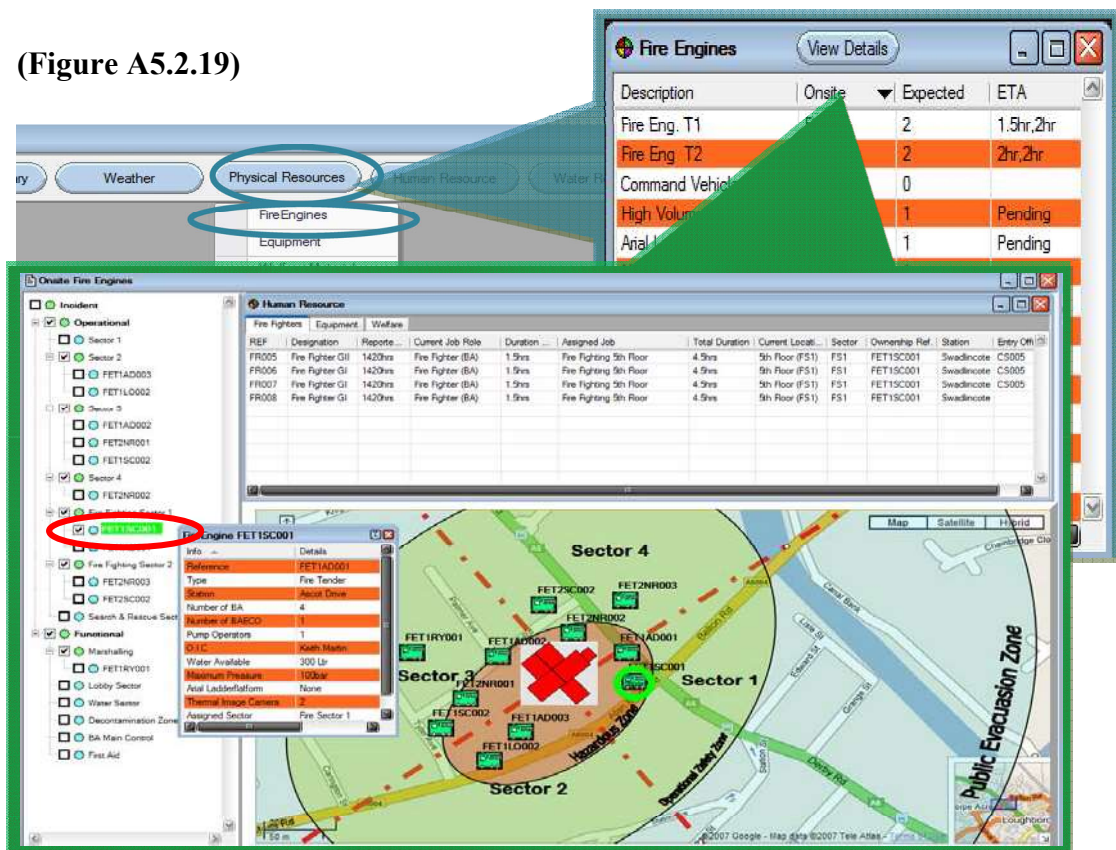


Interface Displaying Floor wise Distribution of Fixed Resources (Figure A5.2.18)



Interface Displaying On-site Fire Engines and their Resource Details

(Figure A5.2.19)



Multiple Interfaces Displaying Summarised Information (Figure A5.2.20)

The screenshot displays the 'On-site Emergency Information System - Ver. 14/04/2014'. The main interface includes several data panels and resource lists:

- Important Locations:**

| Location | No./Availability | Whereabouts |
|----------------------|------------------|----------------------|
| Fire Assembly Points | 4 places | Sector1, Sector2 |
| Decontamination | Yes | Sector2, Safety Zone |
| Welfare unit | 2min | Sector2, Safety Zone |
- Traffic Condition:**

| Entry Route/Road | Average Delay |
|------------------|---------------|
| Boston Road | 5min |
| Allanmoss Road | 10min |
| Clifford Road | 20min |
| Derby Road | 15min |
- Weather:**

| Description | Data - Remarks |
|---------------------|---------------------------------------|
| Outside Temperature | 20 C |
| Wind Speed | 10mph |
| Wind Direction | N - NE |
| Day's Forecast | Sunny with Short Spells of Heavy Rain |
- HR (Internal):**

| Description | Onsite | Expected |
|------------------------|--------|----------|
| Fire Fighter GI | 8 | 12 |
| Fire Fighter GI | 2 | 1 |
| Senior Fire Officer GI | 4 | 4 |
| Senior Fire Officer GI | 4 | 4 |
| Watch Managers | 2 | 2 |
| Crew Commanders | 1 | 1 |
| Safety Officers | 1 | 1 |
- HR (External):**

| Description | Onsite | Expected |
|----------------------------|--------|----------|
| Police | 8 | 8 |
| Explosives Experts | 4 | 4 |
| Paramedics | 4 | 4 |
| Decontamination Specialist | 3 | 3 |
| Chemical Experts | 1 | 1 |
| Building Officers | 2 | 2 |
| Client Representatives | 2 | 2 |
- Dynamic Internal Hazard Summary:**

| Parameter | Details |
|----------------------|---------------------|
| High Rise | 15 floors |
| Type of Business | Shopping Mall |
| Age of the Building | 30 Yrs |
| Confirmed Inspection | 13, 50 - 11/08/2007 |
| Entry Officer | HO G II |
| Fire Risk | V.High |
- External Conditions:**

| Type | Number | OIC | Remarks |
|-------------|------------|-----|---------------------------------|
| Sector1 | Defensive | SC4 | |
| Sector2 | Offensive | SC5 | |
| Sector3 | Offensive | SC3 | |
| Sector4 | Transition | SC6 | |
| Hazard Zone | | | Optical, Shortest Boundary 100m |
- Physical Resources:**

| Resource | Count |
|-------------------------|-------|
| Fire Fighting Operation | 8 |
| Functional Operation | 4 |
| Command Operations | 2 |
- Current Operational Activities:**

| Activity | Location |
|-----------------|----------------------|
| Whearabouts | 5th floor, 8th floor |
| Search & Rescue | 7th floor, 8th floor |
| Ventilation | 2nd floor |
| Salvage | 8th floor |
- Current Functional Activities:**

| Activity | Location |
|-------------------------|------------------------|
| Whearabouts | OIC |
| Safety Cordn. Sect... | O.I.C. Paramedics |
| Safety Cordn. Sect... | O.I.C. Decontamination |
| Safety Cordn. Sect... | O.I.C. Command Support |
| Ground Floor - Entra... | O.I.C. BA Control |
| Safety Cordn. Sect... | FSC5 |
| Safety Cordn. Sect... | FSC3 |

Additional Interface for Enhanced SA (Figure A5.2.21)

Important Locations with the Building

| Floor (Sector) | BA Boards | ECP | Access Points |
|----------------|-----------|-----|---------------|
| GF | | | |
| 1st | | | |
| 2nd | BH | | 2 Points |
| 3rd | | | |
| 4th | | | |
| 5th | IS | | 2 Points |
| 6th | IS | | 3 Points |
| 8th | SRS | | 2 Points |
| 9th | SRS | | 2 Points |
| 10th | | | |

Fire Fighting Operations with the Building

| Floor (Sector) | Type of Operation | | | | |
|----------------|-------------------|-----------------|-------------|--------------|------------------|
| | Fire Fighting | Search & Rescue | Salvage | Ventilation | Emergency Backup |
| GF | | | | | |
| 1st | | | | | |
| 2nd | BH | | | | 6BA |
| 3rd | | 2BA - 1Team | 2BA - 1Team | | |
| 4th | | | | | |
| 5th | IS | 8BA - 2 Teams | | | |
| 6th | IS | 10BA - 3 Teams | | 6BA - 1 Team | |
| 8th | SRS | 8BA - 2 Teams | | | |
| 9th | SRS | 8BA - 2 Teams | 4BA - 1Team | | |

Fire Fighting Operations outside the Building

| Floor (Sector) | Type of Operation | | | | |
|----------------|-------------------|-----------------|---------|-----------|------------------|
| | Fire Fighting | Search & Rescue | Salvage | Ventilat. | Emergency Backup |
| GF | 5 | 2 | 4 | | 4BA |
| 1st | 7 | 2 | 4 | | |

Data Input Interface to Create & Edit Tactical Modes (Figure A5.2.22)

Outside Map of the Incident

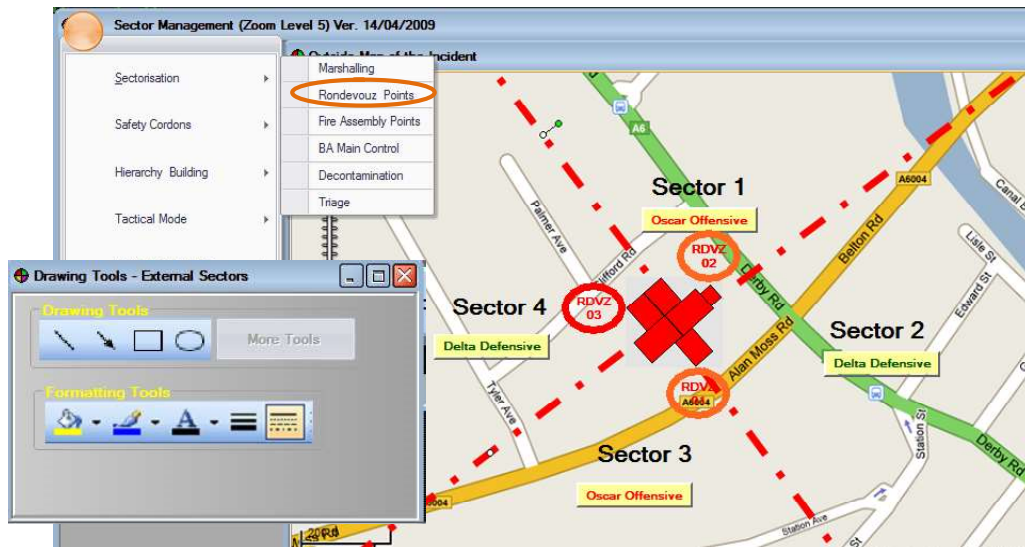
Map Legend:

- Sectorisation
- Safety Cordons
- Hierarchy Building
- Tactical Mode
- Risks and Hazards
- Functional Zones
- Close

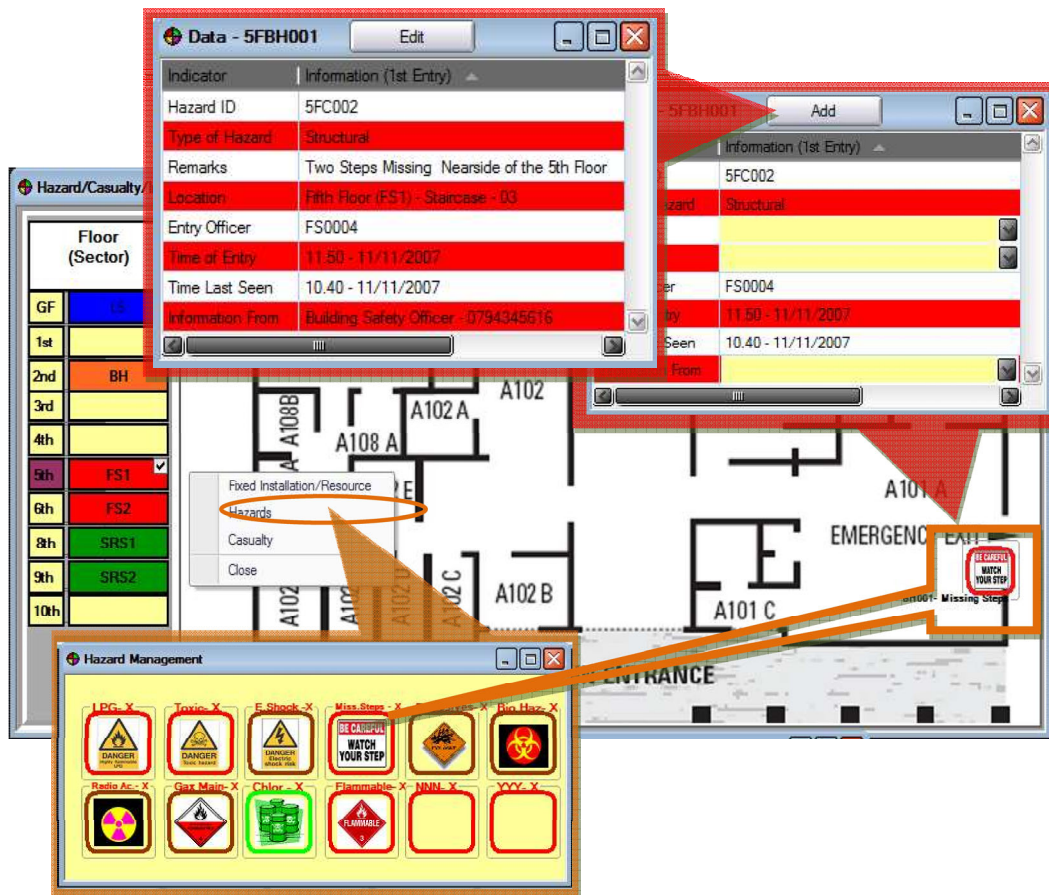
Map Labels:

- Sector 1: Oscar Offensive
- Sector 2: Delta Defensive
- Sector 3: Oscar Offensive
- Sector 4: Delta Defensive
- Outside the Building
- Inside the Building

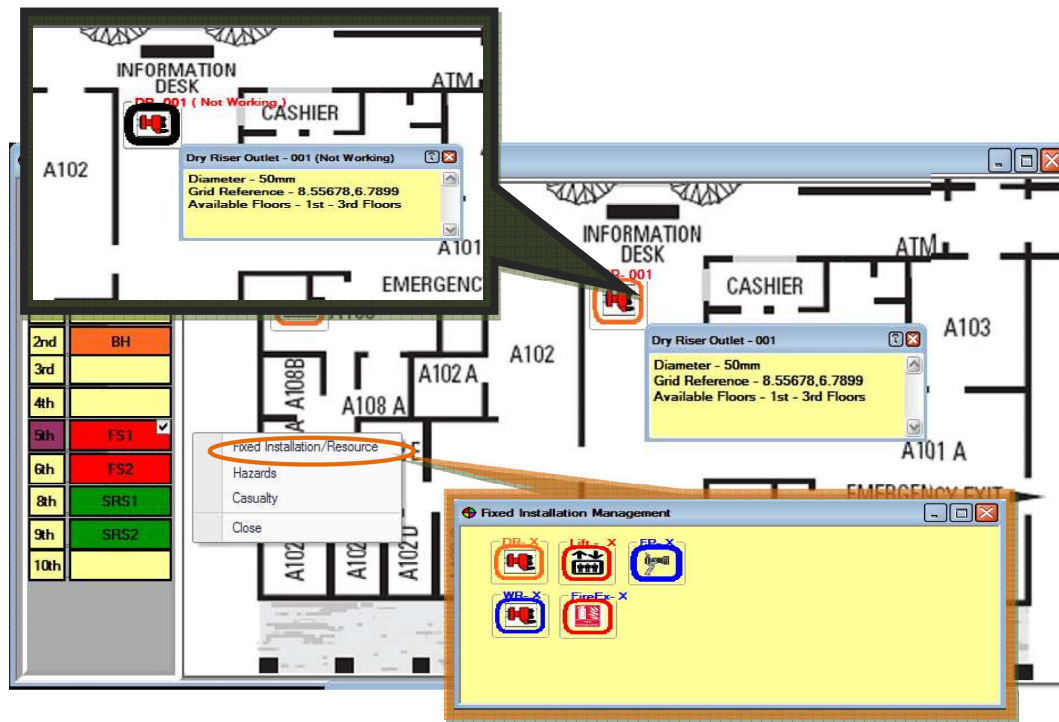
Data Input Interface to Add, Activate and Deactivate Rendezvous Points (Figure A5.2.23)



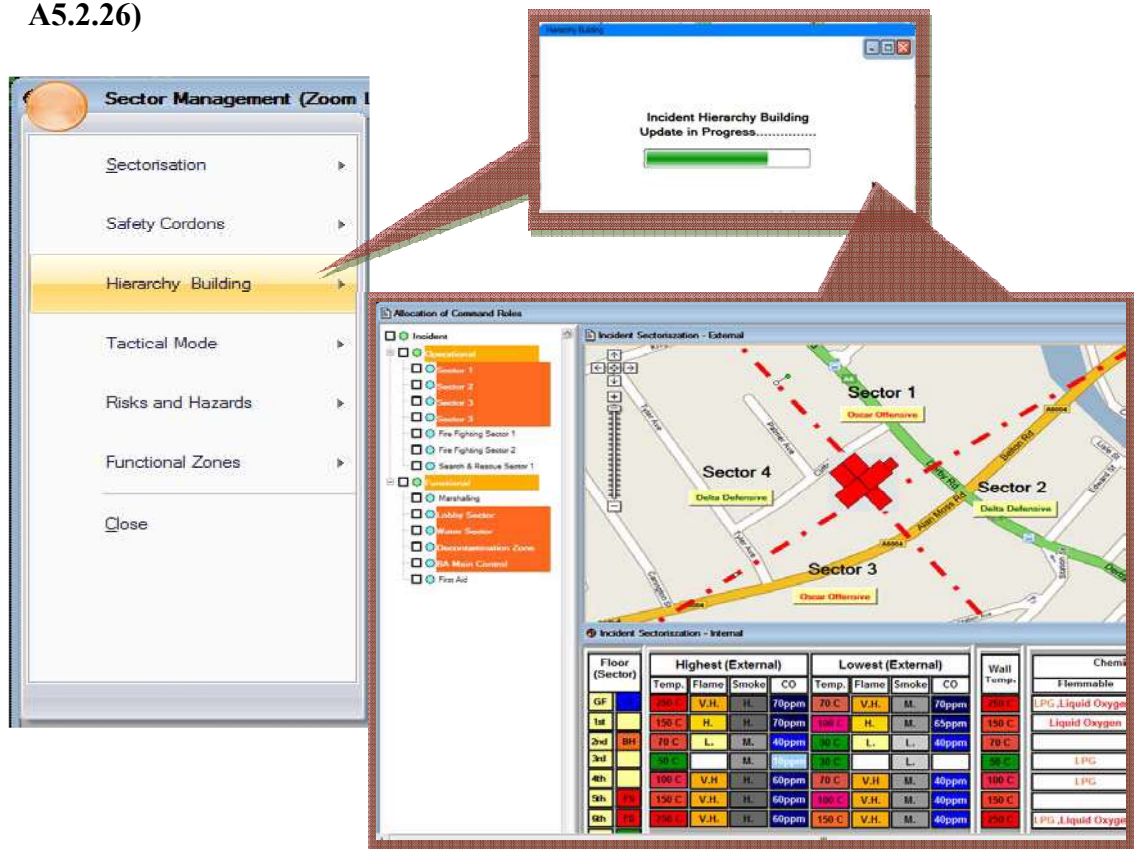
Data Input Interface to Add Hazards Symbols and Data onto the Map Layer (Figure A5.2.24)



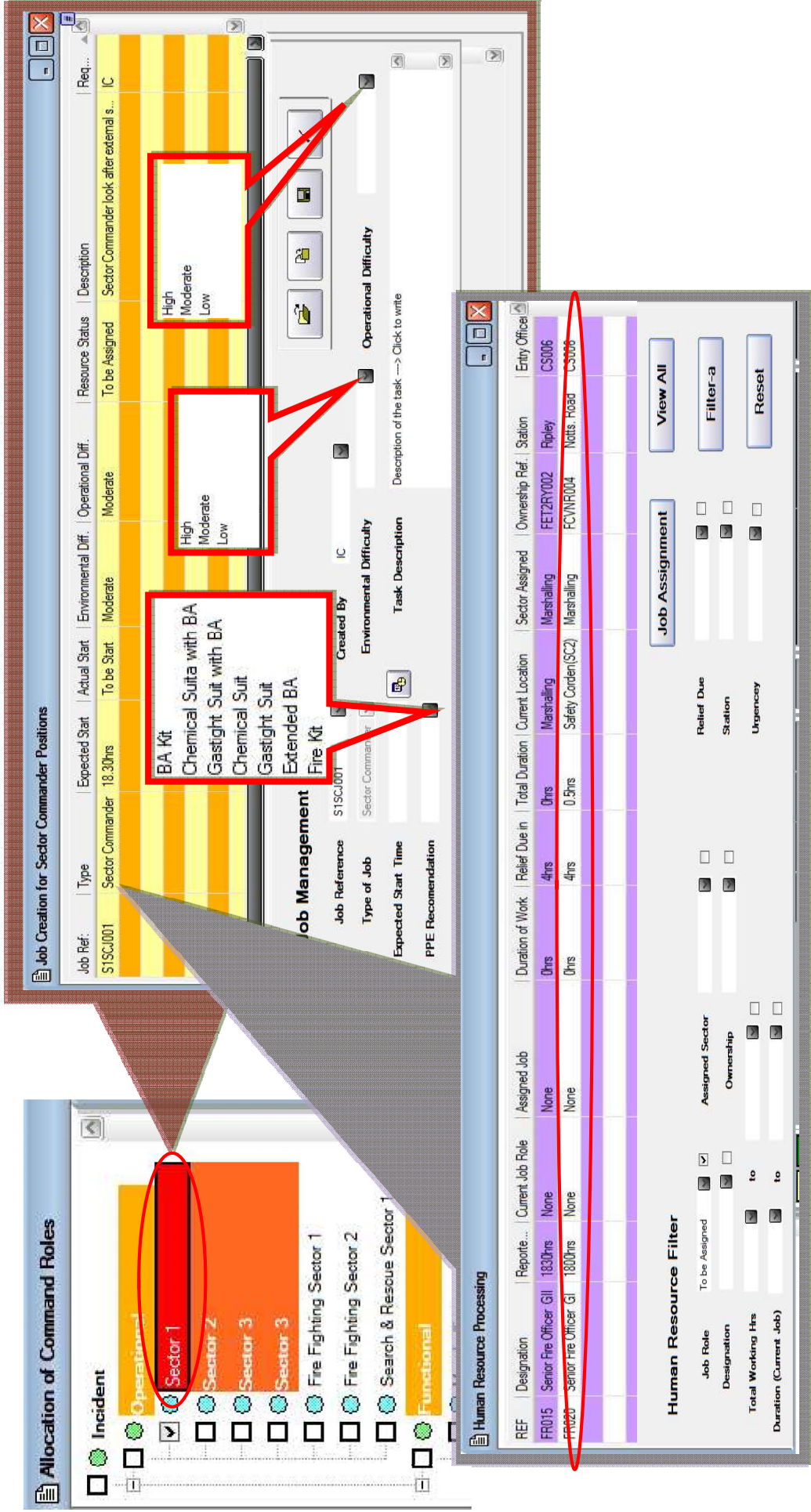
Data Input Interface to Change the Status of Fixed Resources/ Installations (Figure A5.2.25)



Data Input Interface to Build the Incident Command Hierarchy (Figure A5.2.26)



Interface to Create SC Jobs and Allocation of Human Resources (Figure A5.2.27)



Interface to Create Jobs within the Designated Sectors and Allocation of Human Resources (Figure A5.2.28)

Job Design and Resource Allocation - View

| Job Ref. | Type | Actual Start | Expected Start | Environmental Diff. | Operational Diff. | Resource Status | Description |
|-------------|------------------|--------------|----------------|---------------------|-------------------|-----------------|-------------|
| FFSZSC01 | Sector Commander | 10.30am | 10.30am | Moderate | Moderate | Allocated | IC |
| FFSZBAECO01 | BA Entry Control | 10.35am | 10.35am | Moderate | High | Allocated | IC |
| FFSZVTJ001 | Ventilation | 10.40am | 11.10am | High | Moderate | Allocated | IC |
| FFSZFFJ001 | Fire Fighting | 11.00am | 11.40am | High | High | Allocated | IC |
| FFSZFFJ002 | Fire Fighting | 11.40am | 11.40am | High | High | Allocated | IC |
| FFSZFFJ003 | Fire Fighting | To be start | 11.30am | High | High | To be assigned | IC |

Job Management Form

Job Reference: FFSZFFJ003
 Type of Job: Fire fighting
 Expected Start time: []
 PPE Recommendation: []
 Created By: IC
 Environmental Difficulty: []
 Task Description: []

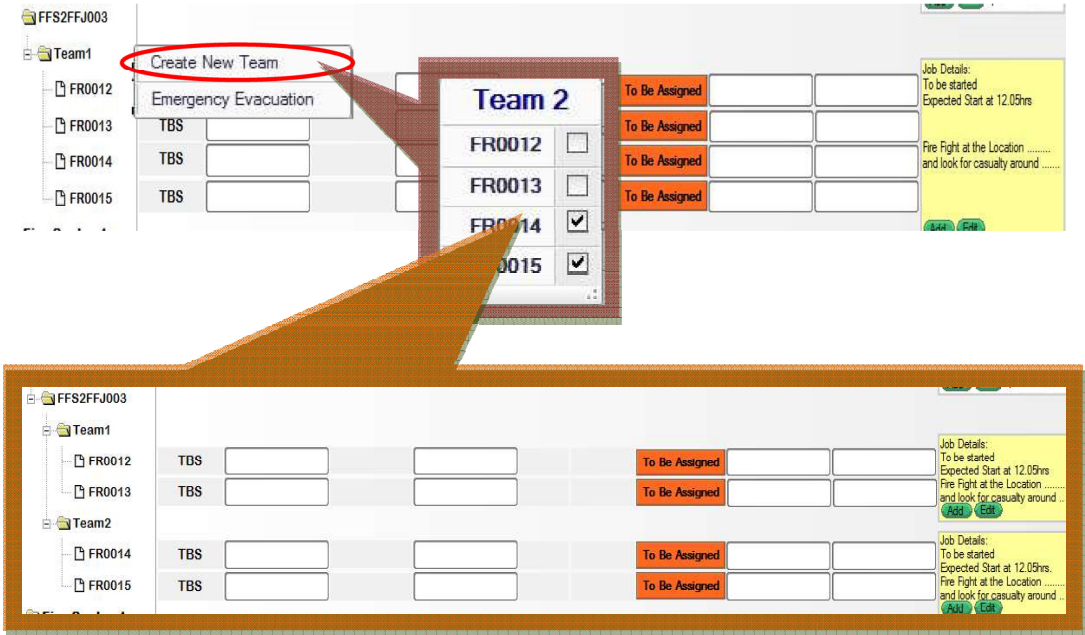
Job Assignments:

- Fire fighting job 01
- Fire fighting job 02
- Fire fighting Job 03
- Ventilation job 01
- Search & Rescue Sector 1

Interfaces to Manage Resources (Figure A5.2.29)

The figure displays several overlapping screenshots from the 'IC Resource Management Module - Ver. 14/04/2009' software. The main interface at the top shows a 'Request Status - Fire Engines Requests' table with columns for Request Ref., Description, Requested By, Assigned to, Time of Request, Expected at, Level of Urgency, Request Status, and Status (Expected Time). Below this is a 'Request Filter' section with checkboxes for 'Assigned to' and 'Status (Expected Time)'. A 'Human Resource Processing' window is overlaid, showing a detailed table of resources with columns for REF, Designation, Current Job Role, Assigned Job, Reported, Duration of Work, Relief Due in, Assigned Relief, Sector As..., Current Location, and Entry Office. Other windows include 'Fire Engine Request Form' with a 'Human Resource Filter' and a list of resources like 'Incident', 'Operational', and 'Fire Fighting Sector 1'. A 'Request Filter' window shows a list of requests with columns for Request Ref., Description, Requested By, Assigned to, Time of Request, Expected at, Level of Urgency, Request Status, and Status (Expected Time). A 'Human Resource Processing' window shows a table of resources with columns for REF, Designation, Current Job Role, Assigned Job, Reported, Duration of Work, Relief Due in, Assigned Relief, Sector As..., Current Location, and Entry Office. A 'Request Filter' window shows a list of requests with columns for Request Ref., Description, Requested By, Assigned to, Time of Request, Expected at, Level of Urgency, Request Status, and Status (Expected Time). A 'Human Resource Processing' window shows a table of resources with columns for REF, Designation, Current Job Role, Assigned Job, Reported, Duration of Work, Relief Due in, Assigned Relief, Sector As..., Current Location, and Entry Office. A 'Request Filter' window shows a list of requests with columns for Request Ref., Description, Requested By, Assigned to, Time of Request, Expected at, Level of Urgency, Request Status, and Status (Expected Time).

Interface to Create Multiple BA Teams (Figure A5.2.30)



Alarm for Resource Request Management (Figure A5.2.31)



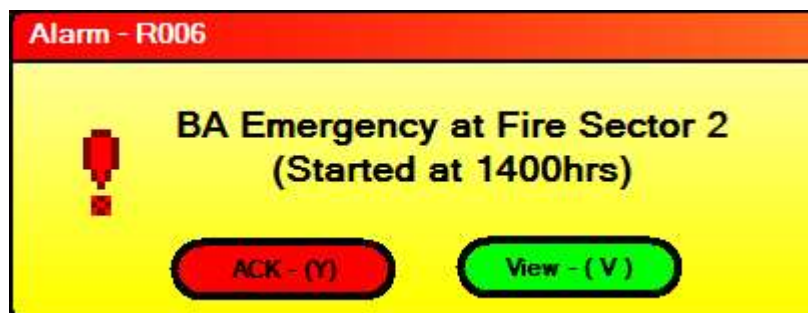
Alarm for Request Delays for ICs (Figure A5.2.32)



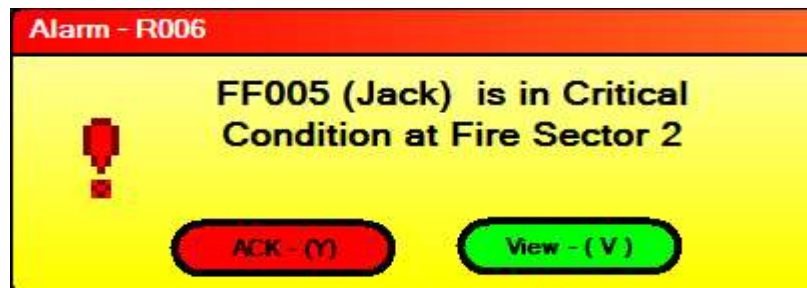
Alarm to Indicate Hazards and Emergencies for ICs (Figure A5.2.33)



Alarm to Indicate BA Emergency for ICs (Figure A5.2.34)



Alarm to Indicate the Condition of Crew Members for ICS (Figure A5.2.35)



Interface for BAECOs to Initiate Emergency Evacuation Alarms (Figure A5.2.36)

Team BAECO 1 (Main Interface) with New Teams Ver. 14/04/2009

Working Progress Work History Other BA Boards Near by Opreations

BA ECO -1

Fire Sector 2

FFS2FFJ001

Team1

FR0018

FR0019

Team2

FR0020

FR0021

FFS2FFJ002

Team3

FR0022

FR0023

FR0024

FR0025

FR0026

FR0027

FR0028

FR0029

FR0030

Board Level Evacuation

| Start Time | Time for Whistle | End Time | Time After Whistle | Opp.Time | Status | Route of Opp. | Environ. Risk | Body Health |
|------------|------------------|-----------|--------------------|----------|----------------------|-------------------------|---------------|-------------|
| 11.40 hrs | 3min | 12.15hrs | None | 22min | Emergency Evacuation | Defined-Fastest | Moderate | Stressed |
| 11.40 hrs | 1min | 12.13hrs | None | 22min | Emergency Evacuation | Defined-Fastest | Moderate | Stressed |
| 11.48 hrs | 8min | 12.20 hrs | None | 14min | Emergency Evacuation | Defined-Safest | High | Healthy |
| 11.48hrs | 6min | 12.18hrs | None | 14min | Emergency Evacuation | Defined-Safest | High | Moderate |
| 11.20 hrs | | 11.55 hrs | None | 35min | Evacuated | Defined - Alternative 1 | None | Moderate |

Create New Team

Emergency Evacuation

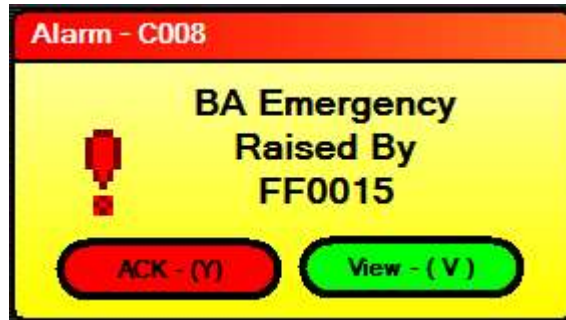
Movement

Mass Evacuation

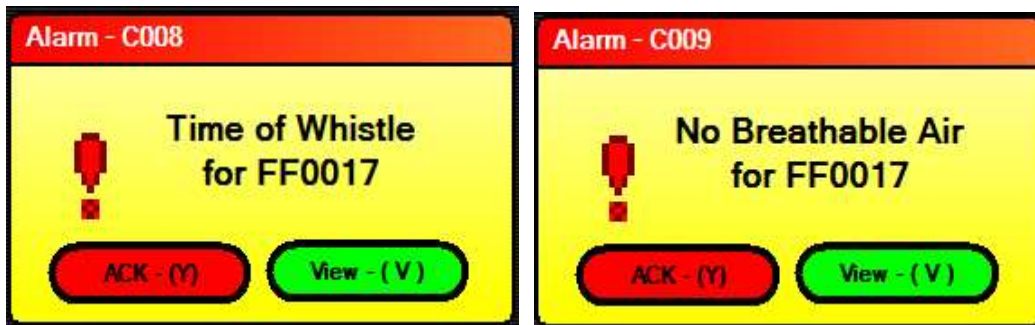
Sector Evacuation

BA Board Evacuation

BA Emergency Alarm Raised By an Individual BA Wearer for BAECOs (Figure A5.2.37)



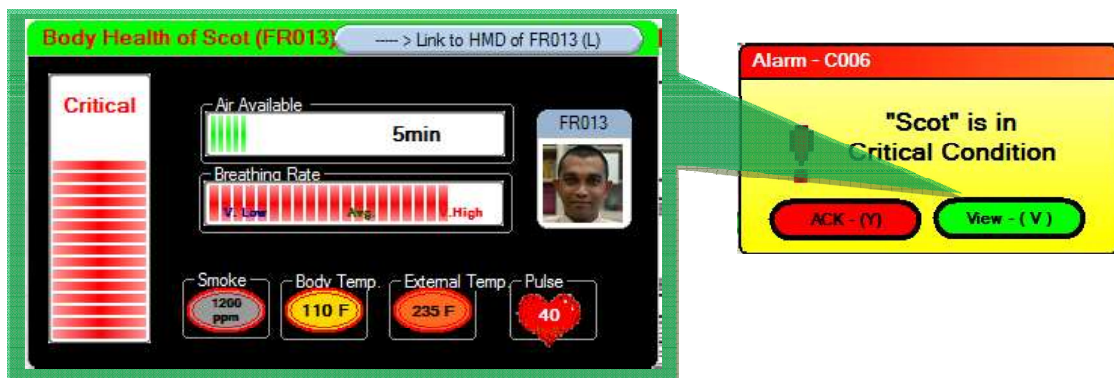
Alarms Displaying Air Levels for BAECOs (Figure A5.2.38)



Alarm Displaying BA Wearer Evacuation via a Different BA Board for BAECOs (Figure A5.2.39)



Body Health Alarm of a BA Team Member for BA Wearers (Figure A5.2.40)



Appendix 6.1: List of SME's selected for the Human Computer Interface Mock-ups Evaluation Sessions

| Session Ref. | Type Participant Type | Job Role | Fire Station | Designation (No. Participants) | Experience |
|--------------|-----------------------|------------------------------------------------------------------|------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------|
| 1 | Individual | Incident Commander/ Sector Commander | Ascot Drive Derbyshire | Area Group Manager | 15 Years Experience as an IC with real-time experience in large building fire fires. |
| 2 | Individual | Incident Commander/ Sector Commander | Incident Command Training School, Market Harborough, Leicestershire | Specialist Training Instructor for IC teams | 10 Years experience as IC and Incident Command Training Officer |
| 3 | Individual | Incident Commander/ Sector Commander | Head Office, Leicestershire Fire and Rescue, Glenfield, Leicestershire | Incident Command Systems Project Manager | 20 Years experience as IC and Incident Command Training officer |
| 4 | Individual | Incident Commander/ Sector Commander | Old Hall, Training School Derbyshire | Command Training Manager | 12 Years experience as an IC and Incident Command Training officer |
| 5 | Individual | BA Wearer/ BA entry Control | Loughborough Training and Development Centre | BA Training Manager | 20 Years of Experience as BAECO and BA Training Instructor |
| 6 | Individual | BA Wearer/ BA entry Control | City North Fire Station, Nottinghamshire | Watch Manager | 22 Years Experience as BAECO with real-time experience in large building fires. |
| 7 | Individual | BA Wearer/ BA entry Control | Derbyshire BA School | BA Training Instructor | 20 Years of Experience as BA Wearer and BA Training Instructor |
| 8 | Individual | BA Wearer/ BA entry Control | Derbyshire BA School | BA Training Instructor | 17 Years of Experience as BAECO and BA Training Instructor |
| 9 | Group | Incident Commander/ Sector Commander | Derbyshire Senior Managers | Station Managers (2) Area Group Managers (3) | 10-25 Year of Experience as a Incident Commander of Large-scale Fires (Bronze and Silver level IC) |
| 10 | Group | Incident Commander/ Sector Commander | Leicestershire Senior Managers | Station Managers (2) Senior Safety Specialist (1) Incident Command Systems Project Manager (1) | 8 – 20 Years of Experience as a Incident Commander of Large-scale Fires. (Bronze and Silver level IC) |
| 11 | Group | Incident Commander/ Sector Commander | Nottinghamshire Senior Managers | Group Managers (2) Senior Risk Response Officers (1) group support officers – training and development (1) Divisional Officers (1) | 12– 22 Years of Experience as an Incident Commander of Large-scale Fires. (Bronze and Silver level IC) |
| 12 | Group | Command Support | Leicestershire Command Support Team | Station Managers (1) Watch Managers (2) Senior Firefighter (1) | 5-12 Years Exclusive Experience as Command Support Officers |
| 13 | Group | Command Support | Derbyshire Command Support Team | Station Manager (1) Watch Managers (3) Senior Firefighter (1) | 3-15 Years Exclusive Experience as Command Support Officers |
| 14 | Group | BA Wearer/BAECO | Derbyshire BA School Training Staff | BA Training Manager (1) Training Instructors (2) | 10-20 Years of Experience as BA Wearer, BAECO and BA Training Instructor |
| 15 | Group | BA Wearer/BAECO | Leicestershire BA School Training Staff | Training Instructors (4) | 8- 24 Years of Experience as BA Wearer, BAECO and BA Training Instructor |
| 16 | Group | BA Wearer/BAECO | Nottinghamshire BA School Training Staff | Training Instructors (3) Training Manager (1) | 10- 18 Years of Experience as BA Wearer, BAECO and BA Training Instructor |
| 17 | Group | Incident Commander/ Sector Commander/BA Entry Control/ BA Wearer | Fire Preventive Specialists – Fire Protection Association, UK | Senior Fire Preventive Consultants (3) | 20-25 Years of Experience in various job roles between BA Wearer- Gold Level IC |
| 18 | Individual | Operating Procedures and Documentation Development Officer | Derbyshire FRS Ascot Drive | Station Manager (1) | 6 Years Experience as a Documentation Specialist |
| 19 | Individual | Operating Procedures and Documentation Development Officer | HQ, Leicestershire FRS , Glenfield, | Watch Manager (1) | 8 Years Experience as a Documentation Specialist |

Appendix 6.2: Guide for the Walkthrough Sessions of IC and SC

Generic Information

- A high-rise building consisting of 10 floors including the Ground floor
- Ground Floor defined as the Lobby Sector
- Second Floor defined as the Bridgehead
- Fifth and Sixth Floor defined as the Fire sector
- Seventh and Eighth Floors defined as the Search and Rescue Sectors
- For the purpose of detail illustration of internal context, the 6th floor is selected

Scenario

999 Call received at the Control Room of the fire and rescue of the county of..... describing a multiple fires being reported at a hypothetical high-rise building located at the Junction of Derby Road, Leicester Road, and Belton Road Junction. The building is a high-rise consisting of 10 floors including the ground floor. It is one of the largest shopping malls in the region comprising of clothing shops, an art gallery, jewellery shops, multi theatre cinema. Built 30 years before, the building recently added its own control room located on the 2nd floor consisting of automated building management system having connectivity to both internal and external CCTV footage. It is very close to the Belton road industrial park, which has several manufacturing plants dealing with chemicals and other fire prone elements.

At the beginning, multiple fires were located in both Fifth and Sixth Floors. Further, casualties were reported on both 5th and 6th Floors. In addition, further casualties were reported on the 7th and 8th Floors.

Assume incident has progressed into its 1st half hour from its 999 call and already 8 Fire engines have attended via pre determined attendance scheme (PDA) and two other engines are on route to the incident. Currently incident ground is divided in to four sectors externally. Further internal fire sector and search sector is already defined. In addition, location for bridgehead and lobby sector is already identified. Apart from external sectors, external area is surrounded by three cordons.

Tasks carried out by the IC

- External and Internal Sectorisation.
- Defining External Cordons.
- Allocate designated areas for triage, marshalling, decontamination and further introducing new rendezvous point.
- Defining Top-level Incident hierarchy and allocate sector commanders.
- Requesting and Authorising additional fire engines.
- Obtain overall understanding of prevailing situation at the incident.

Assuming selected SC for this scenario walkthrough is responsible for the operations carried out in the 6th floor,

Tasks carried out by the SC

- Looks after the progress of fire fighting operations currently carried in the 6th floor.
- Maintain understanding of the casualty and salvage related operations.
- Create new jobs in the 6th floor and assign appropriate resources.
- Make new request for fire engines.

Appendix 6.3: Discussion Guideline – Human Computer Interface Mock-up Evaluation

Topic 1 - Performance of the Mock-up Interfaces

- Check whether the support of proposed mock-up can bring improvement to the decision-making and overall effectiveness of the operations of respective job role by asking similar questions as shown below?
 - *What is your opinion about the mock-up interfaces with regard to its ability of supporting decision-making and therefore, increasing the effectiveness of the performance of the response activities?*
- Check any shortcomings of the performance of the mock-ups and identify how to overcome such shortcomings by asking similar questions as shown below:
 - *Have these mock-up interfaces managed to capture information requirements during high-risk fires? Is there anything missing?*
 - *Can you find any invalid or non user friendly display of information in any of the interfaces?*
 - *How can we improve such shortcomings or limitations? How can we solve such issues?*

Encourage the participants to discuss the above topic focussing specifically on the following categories of Mock-up Interfaces.

For the IC and SC Job Roles:

- Mock-up interfaces capable of providing information on the external environment
- Mock-up interfaces capable of providing information on the internal environment
- Mock-up interfaces capable of providing summarised information
- Mock-up interfaces related to generating useful alarms
- Mock-up interfaces capable of supporting data input
- Mock-up interfaces capable of recalling the interfaces with the past data (Black Box)

For the BAECO Job Role:

- Mock-up interfaces capable of providing information on the external environment
- Mock-up interfaces capable of displaying the performance of a BA Entry Control Board.
- Mock-up interfaces capable of generating useful alarms
- Mock-up interfaces capable of supporting data input

For the BA Wearer Job Role:

- Mock-up interfaces capable of providing information on the external environment
- Mock-up interfaces exclusively providing support frontline fire fighters as and when carry out their operations.
- Mock-up interfaces capable of generating useful alarms
- Mock-up interfaces capable of supporting data input

Topic 2 - Possible design failures due to SA Demons and how to avoid them

- Is there any possibility of information overload with regards to this type of interfaces?

(Check the impact of information Overload)

- Is there any possibility that this type of interfaces could take away your attention from important information by providing unnecessary attention to other less important information? (*Check the impact of attention tunnelling*)
- Can these interfaces have impact on your work related stress? How can your work related stress affect the use of these interfaces? Can this type of interfaces serve during high-stress type of operations? (*Check the impact of whether Workload, anxiety, fatigue, and other stressors (WAFOS) during the operation can have any impact on the use of these interfaces*)
- Have these interfaces given enough prominence to access most critical information? Can you identify critical information correctly and speedily via the interfaces? Can you recognise balance of using colours, sounds, icons during information presentation (*Check the impact of Misplaced Saliency*)
- Are these interfaces too complex to operate, can you figure out easily how to operate each feature or function of the interfaces and exactly figure out its output? If yes, please highlight? (*Check the impact of Complexity Creep*)
- Can these interfaces stop or prevent you from keeping you away from the situation not allowing you to take the control of the situation? Are you totally dependent on the system to carry out your work? Is there any possibility for you to take the control? (*Check the possibility of out of the loop syndrome*)
- Do these interfaces require you to remember too many things when making decisions or do they actually require less memory power compared to the situation where you don't have a support of an information system of this nature? (*Check the impact of requisite memory trap*)
- Is there any interface which can wrongly model the actual situation therefore lead to misinterpretation of information? (*Check the impact of the possibility of Errant Mental Models*)

Topic 3 - Perceptions in relation to the Controllability and Deployment of the interfaces

- What sort of mechanism do you like to have for better and easy control of the system?
- What type of devices do you like to use for the purpose of deployment of these types of interfaces?

Appendix 6.4: Selected Transcript Fragments Associated with the Themes Related to Relevance and the Impact of the SA Demons Related to the Design of the System

Finding 1: SA Failures due to Information Overload

Session 1

b.1. – S1.F1

Information overload can be a real issue when it comes to any system you try to give it to us, especially when you consider the very little time we have at the incident ground compared to any person who makes decisions sitting in a nice and comfortable office room. So more than ever, you need to think the way you arrange information on an interface. It can be more difficult as an IC or a SC..... our approach to the operations can vary depending on the progress of the incident itself and also with the amount of support you can get via the delegation of responsibility. Further, there can be rapid and sudden changes to the incident complexity. Therefore, you can imagine within very short period these differences further can create variations to the amount of information we need. So if any system to become successful it must adapt to these changes and must be able to provide only the needed amount of information nothing less nothing more. Too many information that don't have any relevance may definitely going to clutter or way of thinking. It add more challenge unnecessary making us scratching our heads more and asking us to pick and choose the most relevant and important information. Ideally, this should never happen in any system, but with our type of work, it should never happen in practice as well. So with more and more unnecessary picking and choosing options our minds will definitely get tired and frustrated. So systems must think of a way to only provide the most essential information that required.

Session 2

b.1. – S2.F1

Actually, your prototype has given the choice of selecting any type of information with the help of the given menus. Actually it is not forcefully giving you information, by attaching information into many number of different layers, and by providing menus classifying information into very useful classes of information, it has given lot of room for the user to select only the information he wants to select.....apart from the alarmsprototype never throws information at you...you have the choice of selectionthis is really good..... that is definitely one way to reduce the information overloading of ICs and SCs.

Session 3

b.1. – S3.F1

Information overload can be a really mess ...even today with the minimal systems we have to collect information there can be massive information overload... that is mainly because as we don't have reliable sources of information we tend to collect lot of information from multiple sources and tries to filter out and in parallel try to build a some sort of a picture of the incident both in and out. So information overload automatically happens as we have to always juggle with duplicate information from many sources from which we have to make our own picture by filtering out unrelated and unreliable information on our own. Definitely, it is going to put lot of pressure and stress on our minds. In that manner what we have got here is definitely a better solution.... if the accuracy of the technology is correct we may be able to get lot more accurate information from this type of system....so that is self will reduce us getting intentionally overloaded by information....why..with this we may not want to have that many sources to tell us what is happening....the massive filtering we are currently doing can be reduce drastically with this sort of system..... on the other hand, about the information overloading this system aloe can create.....what I think is it is very low.... I think the way you delivering information is really good... system most of the time start with completely a empty blanket of information but you have given very user friendly categories of information from which end-user can pick and choose what he wants on the screen. System has divided information on to very small layers but arranged in a way that end-users can call them on top of each other to make a very quick picture of what is happenings. I think really good.... the things forcefully comes to you is only the alarms.... that I think is essential.... so nothing is forcefully delivered.... but yet I think you have managed to maintain a balance by providing useful mechanisms to call the right information on to a display rapidly... so if we talk about this system it is definitely not overloading us with information..... compared to our current position definitely it is going to reduce the information overloading to a much greater extend.

Session 4

b.1. – S4.F1

Information overloading can be a real issue here specially when we are dealing with thousands of information pieces within very short time.... but importantly we don't all of them at once on a screen... what we want is the information matched to the current targeted we try to achieve..... if talk about this particular system.... we think you have managed to reduce it drastically.... specially by arranging information into various layers and giving a very flexible menu system to calling them according to the wish of the user.... I don't think from what we have seen here that it is going to create any information overload.... but we don't know how it is affecting other job roles but definitely not for ICs and SCs. You don't force information to the information but given simple options to call any type of information very quickly to build a meaningful picture. We thought that is very good way to reduce information overload....If we compare with the current situation... with this system it definitely going to reduce overall information overload.... specially if you think other means of getting the information... at the moment we struggle to collect lot of information..... most of which we can't trust as reliable and therefore, have to go through lot of filtering..... it is actually a kind of intentional information overload... without that currently we can't survive in our decision-making... but with the new system such over load can be reduce to a minimum.....purely because the information proposed by the system can be more reliable... (laughing)... and also to picturing of an situation may only need one or two key strokes compared to lot of pre processing we have to do with our current supply of information....

Session 5

b.1. – S5.F1

.....information over loading is really a problem.... I think we have discuss earlier... there can be some improvements you can do specially about BA Wearer interfaces... but the interfaces you have provided us on route to the incident is really good we have a choice of selection ...by combining several layers of information with maps and plans we can have comfortable and appropriate level of information to make a decision....

Session 7**b.1. – S7.F1**

I think we discuss this under the short coming of both BA and BA wearer interfaces... as I said definitely you can avoid some possible information overloading by removing them from the screens.... you have shown a better approach by giving lot of flexibility to select the information as when fire fighters on their way to the information.... such flexibility of selection is important.... yes for quick capturing you need simple and user friendly menus... I think what you have given is not too bad....

Session 8**b.1. – S8.F1**

Yes information overloading can be very frustrating....I admit the some of the information you have given on the BA board may not have that much of an impact on the decision-making and may unnecessary. I can give you one or two examples....mmmm. ...*time to end* may not be necessary as we don't wait till the end to make our decision related to the safety of fire fighter.... you have given enough other information to make a better decision.....If you are also going to consider the environmental condition to work out the body health indicator of fire fighters they in such a situation there is no need to display the environmental conditions as a separate scale..what we really want to figure out is the condition of the fire fighters.... if you can do it by giving a composite scale that may be enough at this level of information... you see you always have the option of getting a breakdown of the reasons causing such unhealthy conditions by accessing one of the different screens ... if I can remember correctly that was the screen called *profile of the fire fighter*.... but if you only consider the air levels, body temperature and other parameters exclusively related to the body of the fire fighter then it may be O.K. to display two separate scales. So ... you see you'll have to be really careful....it might easily create information overload by showing unrelated information as well as direct or indirect duplication of information..... apart from these areas how you have given the option to call for different pieces of information rather than system pushing information at you ... as I have mentioned earlier... as a BAECO or BA Wearer I have the option of selecting information what I want... that is really good ... in that way you can reduce the information overload to a much greater extend.

Session 10**b.1. – S10.F1**

Information overload is always there with our current supply of information.... one thing is they are not accurate enough ... so we tend to gather as much as possible clues from various sources before making judgment of its reliability ...or we may have to put many pieces together from various sources to make it a useful piece of information.... then only we use the it for our decision-making.... so with limited time it will be impossible to process such enormous amount of information.... so what happens is that we may have to drop some information.... and there is a possibility that the information we drop could become crucial to make the decision better..... so it is very important to provide the most appropriate information to make a decision.... compared to that we have got at the moment proposed system can definitely bring lot of improvements to reduce the information overload.... I feel the current system can manage to minimise our current information overload issues.... so don't try to overdo it in your system.... it might create a situation that system is not giving the most needed information quickly enough.... so it is essential to keep a balance on the delivery of information...not too much ...but also not too little....

Session 11**b.1. – S11.F1**

....what is proposed can minimise most of our current information overload issues.... we don't see you need extra effort to improve that.... and remember not to do it too much as it might create a situation that system is don't delivering the expected amount and type of information as when they most needed..... that can create totally different type of issues....

Session 12**b.1. – S12.F1**

With the limited time we have for making decisions ...ICs or SCs can become easily overloaded with information.....specially current method we are using not always give always us accurate information always this makes IC to capture information from many sources to before they make a solution.... so this may make things even worse... use information from many sources , most of which are similar or duplicate ... and to make a decision in unbelievably shorter time.....more often it will be more than what we can process inside our head ... so obviously we may lose lot of information.... danger of this is we may lose the most precious and most accurate piece of information and therefore, may process more unreliable information to arrive at a decision.... so compared to that what you have proposed is wonderful I think.... with this system by calling one or two graphical interfaces you can make a better judgment very quickly... but with this sort of system ...to get to this sort of graphical image explaining the situation.....may not be on a screen... but at least in your head ...you may have to process enormous amount of information which easily overload your mental capacities....

Session 17**b.1 – S17BA.F1**

..... We can see in general the screens you have proposed to deploy to our mobile data terminals are much more flexible ... it give the choice of selecting information to us... and you make it more appropriate by providing very much user friendly selection method of information.... yes ... the menus are really good.... pretty much you start nothing on the screen apart from a basic map or building plan... but very easily you can call pieces of information on to that basic information layer and may it meaningful for the job you do at that time.....compared to that the screens proposed for BA wearer and BA ECO is carrying lot more information right from the beginning. So you don't have much of a choice that looking at all of the information... this can be frustrating... specially I don't think it is a good thing to send health indicators back to fire fighter himself.... it may not only too much information but may lead to create additional stress I think we have already discussed this.... Also, we have mentioned about some unnecessary information related to the BA board previously

Finding 2: SA Failures due to Attention Tunnelling**Session 1****b.2 – S1.F1**

Yes very easily ...specially as an IC you can forget to check what is happening in other areas....the amount of things you have to worry is that many ...that is why mainly we want to have proper IC structureit definitely reduce things to be looked after and allow more flexibility for us to track and monitor things ...kind of a balanced manner.but you see it is still too much so for a human to maintain.... O.K. for example you have given this solution called dash board to get an over

view ...it is actually a great idea....but we have only two eyes so those eye usually focused on to a one or two critical issues at that time.... therefore you may access further more on this particular issues..... who knows there can be some other issues that could become critical may be picking up at some other areas..... in those situation you need to quickly shift your attention to that particular information... but if you just provided the basic dash board I don't think it is going to happen.... and therefore, it might take long time before actually we change our attention to this new situations.... and most of the time it may be too late.....and that is where I think you need proper set of alarmsnot too many not too little but for something most critical and important.... I think this system is successful in doing this... it not provided us with alarms ... it keep track of them so we can check any time what are the critical issues that still need our attention....

Add few more points with the use of voice alarms to take your attention to the visual display. It is really a good thing to provide the extreme alarming conditions via the voice as well..... this really will help us to maintain our focus ...especially as we can't always keep on looking at these visual interfaces.....you see we need to go away from this talk to other people or to have our own look at the situation... so in such occasion if you can let you know extreme situation via a head piece it will force us to go back to the visual interface for more relevant and detail information.

Session 2

b.2 – S2.F1

I think it is very important to provide us with something like a dashboard.....it definitely push us to keep an eye on many things happening at many places once. Unfortunately we have our white boards fixed inside our command support vehicles which only updated manually.... we don't know whether it covered every bit of important things happening around.... that is why dash board concept is really good... it definitely keep showing us what is happening at every important area of our operations....but problem is still you may keep your focus one particular area of that screen for long time ...I think I mentioned this when we discuss about alarms....but ...you see there are that many topics in that screen....so easily you may forget to check what is happening at other parts of the incident... in a fire incident things may change rapidly... it is never stable.... so you need some sort of mechanism to support you to shift your attention you can focus on the most important information for that particular movement....I think this system has proposed quite smart solutions for such issues....it can provide important alarms and also it can repeat alarms related to situations for which you have not given proper attention.... and also If you miss any important alarms then the list of alarms can also keep your attention to the issues that is not resolved

Session 5

b.2 – S5.F1

Undoubtedly, attention tunnelling may create decision-making disasters.....it could easily happen to fire fighteror it could happen even for an IC ...or simply anybody at the incident... If you realise how fast things happening at a incident and how high is the amount of information you need to keep your attention at once...then you can realise how easily this condition attention tunnelling can become a problem....specially for frontline fire fighter it could easily create a situation of life and death. This is why we think ...although infra red cameras can provide useful information it may be very risky to keep your eye constantly on those screens... it is very important to maintain a proper balance with some other mediumlike voice ... as discussed voice is much familiar medium of communication for us....

Session 8

b.2 – S8.F1

Attention tunnelling can be a killer for the design this type of a system, especially for BA wearers. I have already mentioned this... although you have proposed to mix both voice and visual mediums to avoid this type of attention tunnelling it can still happened if you send to alarms directly to the end-users ... yes whether it is voice or visual it may not make a difference in the case of delivery of an alarms.. as soon as fire fighters realise it as an alarms they will change their attention to that particular to listen or to see and simply forgets what they were currently focusing at... this split of a second may enough to take the life of a fire fighter.....

Session 12

b.2 – S12.F1

I think IC are heavily suffering in their performance mainly due to their narrow attention.... you can't blame them.... we all humans right?.... that is why we are there at large incidents to support them by providing necessary information and help them to shift their attention.... so how we mainly do that is by collecting information and updating our information boards regularly and passing information related to the critical issues that is happening at the incident so that IC can always keep in touch with the most relevant issues.... but you see for us to do that we are not getting appropriate information enough... so what easily happen now is that before IC our attention become too narrow.. and that obviously put ICs in big trouble.... so whatever the system whether it is manual or a system like you it is important to provide with a mechanism to always keep in touch with the most important information....we really think information summaries or as you call it the dash board is really doing the job....on top of that alarms will improve its capability... proper alarms can push us to switch our focus to the most wanted... I think the two in combination can reduce this ...what you call it... attention tunnelling to a minimum.....

Session 15

b.2 – S15.F1

This concept of attention tunnelling can be a real headache for fire fighters.....especially when you want to deliver additional information via things like visual displays....as discussed in many occasion that is why we don't recommend to use the devices like thermal image cameras... it can completely take your attention away from some of the most crucial things happening below your feet.... although thermal image camera is a great piece of equipment.... it can quickly create a disastrous situation....that is why we feel although your proposed system can bring lot of good... if you are not careful in your design it can also bring lot of harm as well.... so carefully balance the technologies to develop a better solution... then it can be very useful...otherwise it can definitely increase the likes of attention tunnelling.....

Session 17

b.2 – S17BA.F1

If I interpreted correctly.... we already discussed this earlier with BA Wearers prototype.....definitely attention tunnelling is directly related to the safety of frontline fire fighters more than anybody else operated at the incident ... especially related to the delivery of information that is why we all concern about only using a visual display.... but what you have proposed here ...to combine both voice with visual would be the ideal...yes as we discussed even voice can take your attention away... certainly yes but it will minimise the lot more worse we can expect by continuously focusing on a visual display.....

b.2 – S17C.F1

.....apart from that, you have proposed a very good suggestion to repeat alarms for un-resolved situations, which need attention of the end-users. This is can be a really good thing as there is a possibility to miss alarms, which are delivered once.... or there can be a possibility for a person to forget monitoring continuously of a situation after some time of its initial alarm.

b.2 – S17BA.F2

.....considering the fact that it can be more often decide the life and death of a fire fighter I think considering attention tunnelling impact in designing this sort of system is a crucial factor.

Finding 3: SA Failures due to Work related Stressors**Session 5****b.3 – S5.F1**

Yes ...Yes ... it is very important for you to consider various types of stressors. It can definitely have some effect how we are going to use the interface. Although your interfaces are really good and can provide information, we never expect to have.... it doesn't matter how good your interfaces are.... we may still not able to read them properly.....I bet you you may not able to stop that.... Yes, I think almost all the stressors faced by fire fighters are mainly related to ones well being... I don't think we concern much about the stressors related to career development ... definitely not at the level of BA wearer may be when you are operating at much higher rank jobs like IC.....so mostly these stressors are generated by the difficult working conditions .mmmm.... also it can be due to excessive working hours as well.....in other words lack of staff welfare.... so that is why I really believe that it is important to provide some facility in this system to maintain welfare of fire fighters.... not only food and drinks... importantly to arrange enough rest... especially when you are going for a big incident this can be very crucial..... starting from the BAECO level this should be coordinated from the top-level.....Yes I can see you have given opportunity for BAECOs or OICs to realise when fire fighters work excessive hours... and it is really good to have some measure of work difficulty as it can help to decide the number of working hours before a break.....so if you can embed these facilities in real-time it is definitely going to reduce lot of work stress.....less stress will give us with a much clearer mind set so we can make better decisions.... on the other hand as I discussed earlier this system can add more stress to the fire fighters and confused our minds further.....for example sending too much or unnecessary information that can create more stress...as we discussed receiving your own body health ..especially when they are already in some sort of a disoriented status.... this can increase their disorientation further.....so most probably what happened at the end is fire fighters become so confused and will make obvious errors in their decision-making....

Session 6**b.3 – S6.F1**

As I mentioned, it can become more scary to send one's own body health indicators back to them.....so not only severe conditions make the use of these type of systems difficult... the information itself can add or generate more stress.....more stress will further reduce our thinking ability... it can put us into a state of confusion so our decision-making can often become faulty.. Yes, I agree with you it is important to find ways and means to avoid the environmental stressors when you access your systems.... but frankly it will be very difficult....you see you don't have lot of control over your environment.... but you may have some control over stressors due to time pressure or welfare... specially the amount of time you work... currently management of work reliefs are not satisfactory...especially when we have to work back to back operations or operations that goes for days....this can be worse with retain fire fighters.....What I gather is that you have considered managing reliefs in your system.. this is definitely one way of reducing our stress.... and related to time pressure, although we can't create time, system can reduce our workload by providing appropriate informationthat is almost like increase of time to make a decision... for example at the moment we as BAECO we always have to calculate time of whistle and on top of that constantly thinking about the working conditions of the BA wearers to get an idea how it is going to vary with time... but now with this system ...you don't have to manually do it anymore....that means ... the time you earlier used can be preserved in the future...yes?...so if you do your design carefully lot of stressors can be reduced as well.....

Session 8**b.3 – S8.F1**

As discussed, you can reduce our work load with proper alerts or alarms.... so reduce workload can definitely help to reduce our time pressures....even the navigation support proposed by the system definitely going to reduce the both anxiety and work load of a fire fighter and at least work load of BAECO... if it works as proposed those options will reduce much of our work related stress..... But there are many other personal stresses you can solve by the systems..... In fact, those stress can lead us to a situation so we may not be able to read the most user-friendly screen of yours..... Independent from the user friendliness or usefulness of your system or any other similar system this danger will be always there... I don't think we may be able to solve it ever.....

Session 9**b.3 – S9.F1**

We have got many years of experience related to the incident ground stressors.... yes ...yes ... it can have many different phases....you see when you have just got a promotion or expecting promotion soon as an IC you will have lot of pressure when you perform... this is unusually can be very high as most of the time there is a superior officer who is closely monitoring how you are performing.... so you can imagine apart from all other pressures you have been watched round the clock....unfortunately you can't control them.... and you'll have to be careful this particular situation may lead to some disasters. The system you propose is excellent I agree but in this sort of a situation event the best systems may not able to provide the support.....there is a lot of chance of making mistakes when you read your information..... but I agree there are many other type of stressors that with a system like proposed can control or can support us to avoid them.... then ...definitely it is going to have an impact on our behaviourwe may be able to think properly so with that sort of support we can make better decisions at the end... classical example is the incident over view you have provide with the *dash board*. As discussed many times, without wasting any precious time if a system can provide such a comprehensive over view of the incident situation, any incident commander would be able to save tremendous amount of time and effort. As you know currently, what happened is that as an IC, you spend.... and in fact waste lot of time just to build this incident overview inside their heads. So can you imagine when system can do it for you ...may not be with 100% accuracy but to a satisfactory level, how much time you can save and how much work load it can reduce... it is enormous... so that itself can release almost two thirds of our stressors as an IC. But currently only option we have to reduce work load as an IC is to quickly delegate your workbut as you know even with best IC hierarchy ... the amount of work load that has to be carried by and IC can be enormous.... So that is where your system could become handy.....

Session 15**b.3 – S15.F1**

Yes it is true that the system may not have lot of control over the physical stressors such as temperature, smoke or noisesystem may not able to change those figure..... with the use of design features such as BA Wearer navigation, especially with the option of identifying the *safest path* end-user would be able to avoid the impact of such physical stressors to a greater level. So with such option fire fighters would be able to take much more safer path so the possibility of getting disorientation could be reduced to a minimum.... that means you can think clearly and therefore, can carry out much better job..... so you may not have control over certain stressors but system may help you to avoid them.....

Session 17**b.3 – S17C.F1**

I think we discussed how things can become worse ...especially for fire fighter if you are not careful with your system design..... rather than reducing stress it can increase stress easily if you are not careful...especially when you send health related information to a fire fighter who is already disoriented... we discussed the harm it can create....more stress may reduce your thinking ability.. that is actually what happens when you get disoriented... you may not be able to think properly and may not be able to make your decisions properly.... mmm about reducing stress.... it will be very difficult to reduce the physical stressors like noise and temperature....but on the other hand things like the concept of *black box* definitely going to reduce lot of work load of an IC... with that they may concentrate on much important events happening at the incident....mmmm.and the proposed solution for managing the welfare of fire fighters ... specially the managing the relief allocation... it can be benefitted to release both the work load related stressors of the senior commanders as well as welfare related issues of frontline fire fighters such as having inadequate amount of rest during a long run operation....it you managed to reduce our stress levels.....it can be any type of job....definitely it will improve our brain power... we may be able to think much more clearly.....

Finding 4: SA Failures due to “Misplaced Salience”**Session 1****b.4 – S1.F1**

Yet it is very important to find out whether you are giving the appropriate position or place in delivering most critical and important information relevant for particular situation. What I feel is you have managed to do it to a certain degree but it can be further improved. Why I'm saying that is when we finalised the information requirements, we never try to identify the order of their priority. I agree that your knowledge gain via our documentations and observing our exercises may have helped you to figure out some of the important information. But you need to improve further. If you don't know, the priority what will happen is that you may try to give equal prominence to all the information ... that definitely may overload us. Another thing that can happen is that since you don't know what exactly the most important information is, you may lose prominence of them or you may give higher prominence to the unwanted information. Both will create lot of confusion in our minds..... O.K. classic example is the delivery of some of the alarms... I don't think it is necessary for IC to receive alarm as soon as one of the fire fighters pass his/her time of whistle... yes it is important immediately for the BAECO, then to the SC but it should reach IC only if there is not enough improvement with regard to rescuing such fire fighter for long period. In fact, if you have a operations commander they it can be better not to have alarm at all but to send it to the operations commander as the last resort. In such a situation, it would be only enough to accumulate such alarms on a list so whenever IC wants he/she can access itI think there is enough room for you to carry out such improvements... but the only way you can do that is by getting some priority for the information needs.

Session 2**b.4 – S2.F1**

I think there can be improvement on the delivery of most important information.....Yes I agree if you don't give most appropriate saliencenot too high, not too low.... during the presentation or delivery of information as an IC you may not be able to assess the current situation properly you may consider some unimportant information as important while the most important information can be neglected due to the low prominence given by the system. This can directly influence your decision-making..... Yes you can use appropriate colour scheme to do that but at first you must have some idea of how an IC is going to interpret these various colours.... you may have to spend some time before you finalise the correct colour scheme.... sometimes colour may not be enough you may have to use appropriate text or more often appropriate abbreviation to provide necessary prominence..... take the default screen you have proposed for the dash board screen ... see how many colour shades you have used, how many abbreviations you have used you should check them before you actually develop the screen... you see some abbreviations may not given us any motivation to read them... but there can be some specific abbreviations or symbols or colours that currently being used you must have some knowledge on such things.... then only you can think of providing the appropriate level of prominence. Otherwise with our all other work we might miss most important piece of information on your default screen. On the other hand, by giving unwanted prominence, system may force us to make errors in decision-making ... and that can be the worst scenario we expect.....

Session 11**b.4 – S11.F1**

You must be very careful when you use various colours, symbols or even voice or visual alerts to change the once attention to the most critical information at that moment.... why....proposed screens may be over do it....too many of those may lead to total shutdown from our side.... we may just ignore them as it is too much....if you take the colours as a example ...you have used so many shades of coloursrather than using too many you could have just highlight the most dangerous or most prominent one that need the attention.... what can happened by using shades you ask us to figure out the differences in prominence in side our head with the use of the colour shades.... this is far too much.... so easiest thing for us is to totally ignore such complexities.... and that is not good... only highlight the most important point... similar to the colours this can be applied to the use of alarms as well....

Session 15**b.4 – S15.F1**

Yes it is very important that we quickly access the most important information or we give our attention to the information relates to the critical most situation at the incident....the only way you can do that is with the use of colours, symbols and alarms.... actually the proposed system use most of them... it is good ... but you must be careful not to use them too much... if you use too much of them ...in fact it will reduce the prominence of information that need the actual attention... so that means there is a possibility you give your attention unnecessarily to minor issue of the incident where as you may ignore

more important issue. And also some times when it is too much you may just ignore the whole system and just go to your basic instinct or common sense... and if that happens that can be serious.

Session 17

b.4 – S17C.F1

It is important to provide correct prominence to information...say with the use of colours or symbols or text. But importantly it must be a scheme we can correctly interpret. If the scheme you use don't have any prominence to us or if we totally miss-interpret them, it can create a major decision-making blunder. Especially when you use colours to show the prominence you have to be very careful as colour blindness may create chaos in interpreting.... take your colourful dash board screen.... how many colour shades you have used.... for a colour blind persons these shades may not deliver any meaning... with that they will find very difficult to detect the prominent piece of information among others.... No... No... I'm not saying what you have given is bad ... yes true along with colours you have use the text and abbreviation to highlight the prominence ... that is actually good... but have you check whether these symbols means anything for us... you must make sure you use the correct text or abbreviation.... I think it is similar in the case of delivering alerts or alarms... when you start getting many of them you must think of a way to give the necessary prominence to the most important or to the most wanted. One way of doing it is eliminating unnecessary alarms altogether.... or initially to consider appropriate job role other than IC to send them...or to have some kind of a design principle to demarcate various alarms

Finding 5: SA Failures due to System Complexities

Session 1

b.5 – S1.F1

I don't think this the prototype you have given for both IC and SC is complex.... it is actually quite similar to what we are using for our day to day work at the office. And importantly the things you use across both IC and SC ...what I meant is icons, symbols, pictures... all are same... that means they are consistent... so if you make it as much as consistent across all the users that again will reduce the complexity.... this is very much important as quite often we have to play many different job roles during an incident... that means we may have to use the interfaces of BAECOS... this is possible... so make sure you maintain some kind of a standard across all the interfaces.... that will reduce lot of issues Specially the unnecessary training...

b.5 – S1.F2

As I mentioned, allocating all the information more around goals may further reduce the issues related to unnecessary complexity.... especially for novice fire officers if you can arrange a mechanism they can directly call for the information only needed for a particular goal then the complexity of your proposed system can be further reduced..... so number of steps you need to remember to obtain the information could be reduced drastically.

b.5 – S1.F3

As discuss earlier try, to put as much as possible information on to a single layer rather than dividing it in to several layer.... I already discuss this..... but make sure not to overdo it and to do it for the most appropriate.... why I tell you this is actually if you try to put all of them in one screen it can be too much....keep a balance....

b.5 – S1.F4

Yes it is important to make the system as much as simple to operate....if somebody suddenly forget to access some vital information or he is not familiar to use it that can create major problems.... you may make wrong decisions or you may take lot of time before you decide on something....or sometimes if when you feel something is missing you may not want to make that decision....or you make unnecessarily take the more safer option at work... all that is not good.

Session 2

b.5 – S2.F1

As I told you earlier training can be essential for this kind of a system...especially when you are using for the first time....I don't think it is due to any specific problem... but what is going to happened is that if the system is complex you may need more and more training... and sometimes even after training you may forget some functionality if the system is too complex... I don't see any major issue regard to that in your system.... but in general by making consistent functionality across interfaces and also interfaces across various job roles can reduce the complexities lot more....

D. – S2.F2

Whether you like it or not there would be some element of training involve with this sort of systems. As long as you make these interfaces simple, and especially consistent among different job roles. This will reduce the time and cost of the training needs ... I guess....

Sessions 3

a.1.2. – S3.F2

You see you have to identify some very important information and consider put them along with symbols... in that way you can speed up the decision-making....

Session 7

a.1.2. – S7.F3

I feel for some important information you have to dig deep.... try to avoid that. Especially, for the interfaces, you proposed to deploy inside our engines

Session 5

D. – S5.F4

.....Other important fact is that if you want to have less amount of training then the system must be less complicated... it should comprise of interfaces simple to understand and use.

Session 9

b.5 – S9.F1

Unnecessary complexity in the system definitely going to limit our use of this system and that means it can have direct impact on our decision-making.... it can take lot of time before we get to our information.... or if you are not sure with some functionality you may try to avoid the making decisions related to such functions....one way you can reduce the time to access the information is by providing a option that system can deliver the information related to the particular target you are currently working... this would be very handy specially when you don't know what information you need to achieve a particular goal...may be due to inexperienceor may be as we mentioned you before it may be due to lack of recent experience related to that particular job or goal....

Session 12**b.5 – S12.F1**

We don't see any drastic complexities... the system you have provide is very easy to use except when you want to access further detail related to a particular hazard you have to click on the icon to call such information.... but problem is that how you get to know that you need to click on the icon to get the information.... this can be some kind of a ambiguity you may have to think of.... what happened is if you don't know this you may not be able to access the information.... sometimes it can be crucial for your decision-making..... and without that, you may not want to make the information.... so you may need some training ...but.... even after the training ... particularly with the type of environment we are working, it could be very easy for one to forget such functionality.....so it is important to avoid or minimise such complexities... We are not saying to avoid doing this but if you can provide as much as possible information on the single display you may not need to go in to further levels unnecessarily.... classic example is the hydrant information... now for more details you have to click the icon.... but you can give some crucial information like size along with the icon itself..... so this will minimise the loss of information in some situations....

Session 15**b.5 – S15.F1**

If system gets too complex, you may forget how to function it properly... think of a BAECO who already deployed 10 BAs that is the maximum... so in such situation if the BA board interface is too complex and if to extract information you have to go to many interfaces or many layers you can easily forget how to do it. So best thing is to provide as much as possible information on to the BA board itself.... I think you have achieved it to a greater extend...

Session 17**a.3.1. – S17BA.F2**

My colleague has mentioned the drawing tool box ... one important thing is to maintain the consistency of the things. You have used the same tool box for all the job roles. I think such small things are important it makes life easy. Mainly, training time can be reduced when you standardise tools like that across the modules. So person who has to switched roles find it easy to work with the system....

b.5 – S17IC.F1

I think when I mentioned about the training I mentioned that if you can have some form of a standardisation then you can reduce the amount of training required.... why we need training is actually to clarify the complex components of the system to the end-users and therefore, to make it more usable to the end-users as when they operate it... so non standardised screens will create lot of complexity as most of our officers may have to play many different jobs within a single operation and there for may need to access different prototypes.... One other way of creating the complexity in most of the systems is to have so many layers to drill down before you get your information. But you have managed to reduce them ... but as mentioned earlier you can improve this further by providing the most important information related to your current target as quickly as possiblemay be if possible by just clicking on a single button.....as mentioned why not categorise the information along with the goals rather than the information categories... definitely this is going to further reduce the complexity for the users.

b.5 – S17IC.F2

The other important thing is that as I mentioned earlier when you want to refer to many windows if you want to get in-depth information that can create unnecessary complexity.....so try to reduce it as much as possible... but on the other hand I can understand if you try to do that too much it can create some other problems.... the display can have too much information to read ... this can confuse the user..... so be very careful.....

D. – S17BA.F2

Training is not new for us... and without training, you never can't think of implementing something new as a concept... particularly for the case of BA wearers... that concept is totally a new one.... important thing is to make training period shorter and simple..... only way you can do that is by reducing the system complexities also it is important to maintain some sort of standardisation not only on various interfaces of a single job role but importantly among different job roles. Such standardisation will minimise extensive training needs when you move up the ladder. For example, if you are familiar with the BA wearer interfaces , then large portion of information contained in BA wearer interfaces are either almost similar or modified slightly when presented to the job role of BA ECO. Even at a much higher-level of IC, you may still have to share and use some similar representations of information. In such a situation, standardisation of information presentation and presentation screens can become vital to make training budes smaller and training programs much simpler as when fire fighter goes up the ladder.

Finding 6: SA Failures due to Out of the Loop Syndrome**Session 4****b.6 – S4.F1**

This issue we have discussed in our earlier meeting as well..... to what extend we are going to rely on this system..... too much reliance can cause us to out of touch from what is happening outside and when needed we may not have enough time to get in to the correct track.... my first question is what will happened if system shut down for some reason.....how quickly we can shift to our manual systems.... but if we have to shift to our manual methods in the middle of an incident we will be in big trouble.... since with this sort of system we may not maintain our white boards... or even we may not want to remember lot of things as the system can carry out most of such work so suddenly, if we want to shift to the manual system there will be huge information gap... with such sudden loss of information source our operations may not survive..... therefore, it will be very important for this sort of systems to have some sort of solution where if necessary fire fighters can revert back to the manual operation.....

Session 5**b.6 – S5.F1**

Yes this system can make us lot lazier ... and after long years of use it fire fighters sensitivity to their surrounding may be reduced to a greater extend.....this is pretty much alright until system works well... but what will happened if sudden your system get busted for some reason... or simply you ran out of power.....what is your backupor simple in the middle of the operation can you go back to your basic methods..... these are the questions you have to answer when you want to develop a system like this.... so best thing would be always to keep a balance of using the system.... ideally rather than system take the final decision allowing as much as possible for us to make the final decision.... I think that will give us the opportunity to keep in touch with the surroundings and what is happening around.... otherwise too much automation ... things like making the final decision of selecting best path to travel inside the building... yes it is good for the system to give it as a

option but always selection of such have to be decided by the end-user and there should be always a option to change the system proposed path with the input of the end-user.... I think you have already given such navigation option ... it is good...it should be not like auto pilot where you completely trust the system navigationthere should be much higher motivation to the end-users of such navigation facility to incorporate their own senses when they be navigated inside.... system must provide enough encouragement for the end-users to use their senses.... yes one way of doing that is not totally rely on a visual display.....but use voice commands in guidance allowing end-users to use their eyes to capture their own information..... such balance is really important.....

Session 15

b.6 – S15.F1

Yes, this is a problem ... even with our available technology.... we don't totally like to depend on them... quite often we have mentioned this..... when using the thermal image camera ...continuous use of such device can keep us away from our senses.... in the long run there is a change we only look at the screen of the camera but not to use our eyes to figure out what is happening around.... best thing would be only to use the camera when it is necessary..... similar applies to any other system...use the system support only when needed but not for everything.... with regard to this particular system I think it is not too bad.... definitely it is good in the case of BAECO.... but even with fire fighters... if you can improve on the visual display by providing a better ... not too much visual imagery..... yes by balancing with voice.... BA wearer module also can be turn into a better systemboth modules provide us enough room for our own contribution for our decision-making....yes it is good that system to carry out some straight forward calculation and some routine stuff allowing us to make more complex decisions.....it is important that system to provide the decision-making support but not to provide the final decision..... why I'm saying that considering the amount of information you may need to decide, system alone may never able to look at all of them... so the involvement of the end-user is essential..... one example I can give you is the route planning.... yes it is good to system to predict a safer path taking in to account some basic hazmat information.... but there can be many things that system may not be able to capture but may actually important in deciding the travel path.....so this is when room for the users input is essential.....

Session 16

b.6 – S16.F1

What you have provided in terms of support has really good balance... it allows us to have enough room for our own input to make the final decision... but you can't have system to make the final decision always.... system can be perfect 99.99% but still it can make a error... so if we are to totally rely on such system it may be good in shorter run... but in the long run it will keep fire fighters away from active decision-making..... we will just become operators.... that is not good at all.....why... the danger is in that sort of situation if system do some mad things ...may be for some reason...operator may not have enough practice or experience to overcome such situation....so that is why we think it is so important to have good percentage of control over the making of final decision.....

Session 11

b.6 – S11.F1

Yes, it is good to have automation but definitely not too much.... we may think as in the 19th century..... but you can see we obviously have lot of concern toward incorporating technology as we always wanted to have our own control to a greater extend... technology should not overtake or over ride our decision-making... most of the previous efforts of systems may not have taken this factor in to account and that may be one reason we are not use to have lot of systems.... it is not that we don't like support systems..... we like them but what happened in the past I think may be people who develop these systems may not consider these factors.... they may just want to push some kind of a technology and by doing so try to take lot of control over our decision-making.....fire fighters never going to like that..... system may be good but definitely we are the people who should make the final decisions but not the system...yes system can take control over things like basic calculation.. and definitely if system can identify people who need relief that is a great thing as at the moment it is impossible for us to properly manage that.....but it should be not like that system identify the area to be evacuated and automatically send the message to the people who are responsible for doing that or going to a further step and send the message directly to the mobile phones of the people who should evacuate. The best way should be to suggest the area to be evacuated to the IC and IC commander make the final decision to carry out the evacuation. IC is the person who should decide whether to go-ahead with the proposed evacuation area or need changes due the factors that system could not capture, or need totally different solution....yes may be due a obvious fault of the system..... and when IC decides the final area to be evacuation then he could directly send the message to the mobile phones of the people who lives in that ... but even with that I'm pretty sure IC commander may going to use additional resources like the support of police in parallel, to visit the each and every home and make sure people have evacuated..... so you can see in fire fighting kind of operation there can be always you need to have enough room for human intervention.

Session 17

b.6 – S17IC.F1

Keep in mind it should be only decision support but system should never make the final decision.... as I mentioned it is always good this systems to become intelligent.... so it can easily provide us lot of options that we never able to consider before in our decision-making... great example is by combining weather report to provide us with a prediction where the smoke is going to travel... or to make you prepared when you change the properties of the type of hazamt to change the prediction of the profile...or it can be the dynamic spread of temperature or CO inside a room...this is really good... these are the things we never expected achieve as humans on our own ... we definitely need systems to provide such decision-making support....but ...but.... final decision-making should be done by the person who is operating the system... definitely by the system itself....why...there can be many things that system may not considered but which is obvious to the end-user....so end-user would be able to improve the predicted model with his own observations to make the final decision....or he can be prepare himself to face much more difficult decision-making to be done in the future....

Finding 7: SA Failures due to Limited Working Memory

Session 3

b.7 – S3.F1

No not at all...compared to what we have to remember now this system actually can reduce lot of things that we have to remember now.....I think this is the most important service this system can provide us....as you know currently we are mainly rely on the voice communication via radio... so whatever the things we received through that we have to remember for quite a while before we actually use them for our planning or decision-making.... but unfortunately considering the amount of information you can expect as an IC you may forget half of it when you actually make the decision.....no... it is

impossible to write notes... yes we can use the white board.... but it is much limited.....one bad thing with our radios is they are spontaneous.... it is very difficult to listen to the message again... yes replay or rewind.....this in fact not only lead us to wrong planning but stop us from inputting much more important information till we finish with using what already in our head.....this is why memorizing things can become even worse....but with this proposed system we can totally free our minds from remembering things..... this allows us to think clearly and in fact it is definitely going to speed up our decisions....the way you have used visual information is really good.... in most of the time system directly gives you the picture in few minutes which in current situation you may have to form it inside your head after taking lot of information in and processing it in your head ... and you can imagine how long it can take..... but now.... we can straight away start with the picture given by the system... and may be in much more relax way we may able to further improve that picture with other information we can get from some other means..... definitely our decision-making is going to be faster and accurate.... and as explained one main reason is reduce amount of things to be remembered.....

Session 10

b.7 – S10 .F1

Yes we all agree things we can remember is very limited.... but as you already experienced as fire fighters we are struggling currently trying to remember too many things....we have too many things to remember even though we managed to reduce it by delegating it to many people in our command team.... that is actually one reason we try to form a good command structure ... try to minimise lot of things to be remembered by a single person... but still it is too much.... so definitely any system that can support us should look after this issue.... I think what we have seen here today is perfect for that.... it has remove lot of things from our mind that we currently try to remember....and presented in a manner you can display and revisit again if you like... what I meant is things like the concept of black box. So our brain will have lot of space to clearly think...hopefully in the future... definitely that is a great thing if we can achieve...other important thing is that things like alarms will make us properly change our attention to the most needed issue. Now what happen is when we struggle to remember lot of thing we can easily forget lot of things ... specially we may loos touch with several important things as when our mind has can only focus on few bits of information.....so alarm is again a good thing as you know now that you may not going to miss the important things that are happening at incident ground... so without a fear you can concentrate on one thing and use our limited brain power to solve one particular thing without working other things... we can be pretty sure that if something goes wrong in some other place it is going to be informed by the system.... this is really good.....

Session 14

b.7 – S14 .F1

At the moment as fire fighters we have to remember lot of things during our operation....this is really difficult... if we focus too much on that we may easily loos touch with our current work or things related to or safety, what is happening below our feet.... lot of things to remember easily can lose our sensitivity to lot of other things happening... I think for BA wearers this is unbearable as so many things happening at very rapid phase around you and things you have to remember is too much for a given period.... so in that sense this system could become very useful.....since we know that outside officers can see what we are doing and where we are , the things we need to remember can be reduce drastically.... so system can help us to concentrate on other things.... also now we have to look our selves more and decide about hazards... in other words we have to generate our own alarms...but now system can generate alarms for us.... more importantly it can repeat those alarms if we miss them or if we ignore them for long.... this is what system must do actually to reduce remembering things....other thing is that rather than list of information which again need further processing, system has used lot of graphical images....so very quickly it can form a mental picture in our heads.... what happen is that we have to process long list of information on our own before we achieve a good mental picture....as proposed by the system graphical images can reduce lot of processing inside our head.

Session 16

b.7 – S16 .F1

... yes we all think a system must look for reducing thinks for us to remember...actually with our brain power currently we are struggling... as a BA wearer we have to always remember the path we have travelled in as we need to evacuate....in parallel we have to keep some important happened until we come out and do the debrief...it is simply enormous... in parallel our life will be in danger if we forget to look around and process some of the information to realise how safe we are and what can happened next.....so now we can easily run off with our memory power....we may lose lot of information... that means we may do a wrong debrief...we may forget how we should evacuate ...the land marks... and importantly because our memory was full we may not react fast enough to life threatening things around us.....so system should look after these things... definitely should not increase them....that is where I think multiple technologies such as voice and visual can play a major role.... rather than relying on one of them the system has shown if you can make the actual system like this.... I'm sure it will reduce lot of burden of remembering too excessive voice information....by incorporating visual you may not want to actually by heart what was the voice guidance... you have the change of seeing it dynamically on a screen....and other important thing is that lot of information we now process to understand what is happening around us or to decide whether things become a hazardous may not need any more as system can process it for us and can send it as an alert.... not only that system can keep on reminding things that we missed or forgotten.....with visual images we straight away can make the decision rather than processing lot of information inside our heads before we mentally make something similar.....

Session 17

b.7 – S17C .F1

I think it is very important to reduce amount of stress you have on your memory purely as a fire fighter you have to remember too many things in very little time. Specifically, if you look at BAs they have on top of quick processing of large information ... somewhere in their heads they have to maintain a memory map of what they have done throughout their operations... this is really difficult... and that is why it is important for a system to reduce such difficulties.... but not to increase them....currently mainly we use the voice for information delivery.... so most of the time we have to remember it at the first instance.... that is where this particular system can help... it combines both voice and visual information quite smartly....also the use of alarms... repeating them when needed... and for ICs to maintain a list of alarms ... these are really good things when it comes to reduce the mental stress...reduce things to remember....but you must be careful not to overdo it... specially the excessive use of visual imagery may create other problems that we have discussed earlier....

b.7 – S17C .F2

I like the way this system uses lot of maps, symbols and graphics to create a good mental picture in our heads.... that is what a system should do.... but not to give long list of information asking fire fighters to take them in and process them to develop their own picture..... if a system can straight way suggest a picture rather than we try to make them.... things would

be much easier ... we may have enough free space in our head to get more information and to further improve that picture our selves... in that manner our understand of the situation can become much accurate and complete.... what happened earlier is that when we have to process lot of basic information before we get to a any sort of mental picture , we may not be able to even think of getting those additional information.... we may just forget such existence of additional information or maybe we just ignore them as we are already full with information.... other danger is that when we have too much thing to process it might spill out some information....simply forget it to process them... that means the picture we form by ourselves may not be accurate..... compared to all that trouble what we have seen can be brilliant..... conceptually it can reduce lot of burden out of our brains..... we may be able to think and see things very clearly and accurately with the support of this kind of a system.....

Finding 8: SA Failures due to Inappropriate Mental Models

Session 1

b.8 – S1 .F1

It is very important to maintain standard terms and scales in the interfaces.... for example you are using PPM for smoke density... you have to check is there any other meaning to the abbreviation of PPM in the vocabulary of fire fighters if it does have different meaning it may create a total confusion...other classic example is you have given hydrant diameter in “mm” this is correct ... but when it comes to pressure we use “BAR” instead of “PSI”..... so very careful when use the scales... please use the standards used by the us rather than something else... yes it is o.k. for the concept when it comes to actual system you have to be very careful... and to avoid any confusion it is important always to mentioned the unit in words..... so that can minimise any wrong interpretation.....

Sessions 4

b.8 – S4 .F1

Yes, this is really a big problem ...if we assume something and if system is giving us something else, it can create a disaster.... in UK, this can happened in many situations ...why... it is common for us to use both metric and imperial scales in combination..... where things can go wrong easily is not to put the measuring unit on the interfaces clearly..... it is very important to clearly specify the scale otherwise we may unconsciously have our own scale in our minds taking that figures in to account and at the end make completely wrong information..... you have used PSI for hydrant pressure ... it is not correct for us we use actually BARs even you state the scale as I mentioned earlier with our difficult work conditions unconsciously we may revert to the scale of BAR in our mind and that could create disaster in our plans for water.... this can be even worse for fire fighter air pressure..... so be careful....

Session 12

b.8 – S12 .F1

Carful with the terms that you used in the interfaces we don't have zones as such we only have the cordons.... wrong use of words may create a wrong picture in our heads.... I'm sure you will be careful to change the measuring units matched with our standards..... so these are the things that can cause lot of confusions..... it is easy to avoid thisstrictly follow our standards....also be careful when you use abbreviations.... fire and rescue is a place where we use lot of abbreviations and symbols.... if your system don't stick to it may create confusion some times... so careful when you use these abbreviations and terms.....

Session 15

b.8 – S15 .F1

You see I have seen you have used PSI instead of BAR for air pressure... actually this is wrong and can create a big disaster.... it is always important to mentioned it in words ...yes that can reduce the errors...but still since the standard we use is bars one can make a error without knowing that he or she is actually making a mistake. So best would be to refer to our documentation to identify the units and scales we are using and make your interfaces according to that..... this will reduce lot of errors in understanding the current situation.....

Session 16

b.8 – S16 .F1

Yes we can realise how much trouble it can cause if you give a wrong picture ... specially related to BA work... you see if we start from the clock of the BA board you have to be very careful to make it a 24 hr clock rather than 12hr one... this simple mistake can create totally wrong picture you see..... one other thing is that I have seen you have used psi instead of bars ...we don't use PSI for pressure it is only bars. It is so simple to avoid generating such wrong pictures... stick to our standards..... otherwise consequences would be really awful.....

Session 17

b.8 – S17IC .F1

Yes, we were discussing this actually.... some terms and symbols you have used are not supporting what we normally use in the FRS. This can be the main reason to suddenly form a wrong pictureor very easily a wrong calculation that may cause a human life...yes this is so easy to happen..... and it is happening now..... So our advice is that to sit down with some officers.... best people would be people who are developing operating procedures or risk documentation... they are the experts.....and to correct the terms and symbolstry and match to what is being used.....

Appendix 6.5: Catalogued Field Notes Relevant to Chapter 6

Catalogued Field Note Ref. 4.2 based on the observations during BA Wearer Training on 13th (Day 1) July 2007



Photo 4.2(1): Train to check the Cylinder Gauge at Time of Whistle



Photo 4.2(2): Cylinder Gauge Display after reaching Time of Whistle

Fire Fighters were trained extensively to check the Cylinder Gauge Display; especially at the Time of whistle (Low Pressure Air Alarm)

Catalogued Field Note Ref. 4.16 based on the observations during BA Wearer Training on 21st (Day 6) July 2007



Photo 4.16: Debriefing BA operation with the support of hand drawn /written diagrams

As illustrated on the photograph and the movie clip *4.16-MOV0309*, during the training it was observed that after each BA operation team members of the BA teams were giving a debrief to their O.I.C. This meeting sometimes included the members of the new BA team who are to continue with the BA operation as the next tem as well as the BAECO. Apart from these manual drawings they use the support of the actual building plans for these debriefs. An important observation was that after carrying out debriefing, these trainees visited the area where operations were carried out and most of the time found out that the descriptions they have given at the debrief is not accurate or missed many crucial information.

When discussed this issue with the relevant instructor, who carried out training operation, he has explained why it is difficult to have accurate information during the debrief sessions.

As you have observed, most of the training teams has given the wrong information. Also, it has lots of information gaps. They found it very difficult to memorize what happened. Actually, it is a skill they should develop. It is important to get as much as accurate information as it will become useful for developing the future operations. So with experience they will learn to master this concept of mental mapping. Tell you the truth it is very difficult, as they have to work in very harsh and hazardous environments. Actually, their main task is to maintain attention to what is happening around, while carrying out the operations. In addition to that, they need to remember information as much as possible related to the activities they carried out and possibly, where and when they were carried out. So often, what happened is that they focus totally on the current job and forget to remember how they have carried out the operation.

Appendix 7.1: Conceptual Data Capturing and Communication Network for a Fire Emergency Response Information System

Sensors and Sensor-based Networks

The findings of this study in relation to the information needs and information presentation requirements expected by the potential end-users clearly indicate the need of having sensors to capture and transmit various location and contextual information related to the environment and firefighters. These sensors could be possibly 1) attached to the building walls or located on the building floor, 2) attached to various equipments and installations and 3) attached to the firefighters moving inside or outside the building.

When it comes to the selection of actual sensor devices to capture the information expected by firefighters, there are different types of technologies and devices supporting various networking platforms and protocols. Furthermore, researchers have identified several characteristics that should be considered prior to identifying the most appropriate devices (Bose, 2009) in relation to a system to be deployed in a unique context. Some of the important characteristics are as follows:

- Processing capability required
- Level of self organising capability required
- Level of power consumption
- Form factor (size)
- Ease of application development
- Programmability
- Mechanical actuation
- Externally executed application
- Cost

Several additional requirements emerge when it comes to successful application of sensors in the environments affected by the fire. Two frequently raised questions during this study are: *Up to what temperatures these devices can operate satisfactorily?* and *How long they can provide accurate information?*

Having considered characteristics and the sensor platforms proposed by the previous research related to ER (Berry et al., 2005; Jiang et al., 2004a; Klann, 2008; Wilson et al., 2007), the following type of sensor platforms are identified as suitable for further considerations:

- Berkeley Mote Platform
- Smart-ITS Platform
- PHIDGETS
- ATLAS Platform

Although it is not strictly a sensor platform, the RFID platform is also identified as a popular wireless platform that is commonly used in various emergency domains. Apart from the recommendations for further considerations and later explained opportunities and challenges faced by these sensor platforms in implementing the proposed IS, it is beyond the scope of this study to identify the specific sensors for the system implementation.

Having identified the sensor platforms, it is also important to identify the most appropriate type of networks, networking technologies and protocols and communication technologies to connect various types of sensors. Most of the available sensor networks are based on a wired infrastructure in which all the sensors are connected by wires to a central data logging unit that is protected from the fire (Upadhyay et al., 2008). This approach is not generally feasible for actual deployment in a large building as the wiring costs are not expected to go down, the arrangement is bulky, inflexible and vulnerable to the fire (Upadhyay et al., 2008). Therefore, there is a major impetus in developing Wireless Sensor Networks (WSN) to capture various contextual and location information in large built environments (Yang and Frederick, 2004; Tsertou et al., 2007). A WSN is a network consisting of sensor motes capable of self-configuring, self-networking, self-diagnosing and self-healing (Zhang and Wang, 2006). These characteristics have made WSN a very attractive solution for a wide range of environmental monitoring, distributed surveillance, health care and control application. However, the findings of the work of Jiang et al. (2004a) and Klann (2008) indicate that firefighters do not like to depend on the information provided by the sensors of a WSN fixed in the building infrastructure. Firefighters interviewed for both “Siren”

and “LifeNet” projects pointed out that they do not like to rely on pre-installed infrastructure of sensors exclusively, but like tools that they can operate and maintain themselves. Therefore, these two projects recommended deploying sensors before or during an intervention of firefighters. However, the “Fire” (Wilson et al., 2007) project was entirely dependent on pre-installed sensors. Moreover, the “FireGrid” project (Berry et al., 2005) describes the importance of using pre-installed sensors within the building walls to capture some vital information related to building collapses.

The extensive field work and discussions carried out across various fire brigades in the East Midlands area of the UK clearly suggest that it is important to have the support of both pre-installed sensors and sensors that could be deployed by a moving firefighter to form the backbone of the WSN suitable for IS proposed. Most of the firefighters believed that the capturing of hazard related information, location of hazard items and assets, which are mobile such as acetylene cylinders in a chemical plant and highly prized heritage articles located in a site like museum, could be carried out with the support of sensors. According to the regulations of the UK FRS, there are always pre-discussed and pre-approved safety plans for high-risk fire sites. These plans are made under the supervision and approval of the safety officers of the FRS. Hence, participants believe that the planning and installation of sensors can be done under the same scheme and can be pre-installed under the supervision of their safety officers. Although FRS does not intend to take the burden of the cost of installing the sensors in the buildings, most of the firefighters agree that it is essential for them to carry some sensors and deploy them appropriately to:

- Strengthen the information flow coming out of the sensors in situations when some of the pre-installed sensors fail due to high temperatures or other hazardous conditions or due to run out of its power.
- Capture information related to newly identified hazard, item or casualty. This can be useful for the firefighters who carry out operations subsequently (Example: Sending a backup rescue team to rescue casualties who were left at a safe location by the firefighters who rescued them earlier).

Hence, it is decided that the IS proposed needs support of a WSN consisting of both pre-installed sensors and sensors, which are dynamically deployed by the firefighters. The WSN should be built-in and around the incident premises to communicate various contextual information such as smoke, temperature, location of physical items and hazards. Apart from capturing various contextual information, it is also important to capture information related to firefighters themselves. This includes firefighter location, their body temperature, pulse rate, breathing, etc. When it comes to capturing of such information related to frontline firefighter, there is a possibility that they may have to carry several sensors attached to their body armour. Therefore, mobile firefighters should become part of the WSN. This information could also be captured by the various types of sensor platforms mentioned above.

Apart carrying sensors attached to their body armour, it is also essential for firefighters to carry other pervasive devices such as Head Mounted Displays (HMDs), throat operated microphones and speakers for their own use. These devices should be able to communicate to each other continuously. Thus, there is a need for a reliable Body Area Network (BAN), especially for the frontline firefighters. Furthermore, since there could be constant communication between team members of frontline firefighters, there is a need for a reliable Person Area Network (PAN). A BAN typically connects sensors and other devices on the body with the wearable computer's central unit (Dvorak, 2008). Usually, BAN sensors transmit very little data and will not require high speed transmission channels. However, for the type of IS proposed, there is a possibility of having wearable audio and visual display devices. According to Dvorak (2008), a BAN consisting of this type of components may require speeds up to 2Mbps. A PAN is a computer network used for communication among devices in proximity to an individual's body (Dvorak, 2008). The devices may or may not belong to the person in question. The reach of a PAN is typically a few meters. When it comes to PAN, it should maintain the communication between the wearable computer and the local environment and in some cases directly between wearable system nodes and the environment, without going through the computer's central unit. In some situations, a PAN may have to maintain the communication between the BANs of two or more nearby frontline firefighters.

Apart from capturing contextual and location information, success of the proposed IS will depend on the accessibility to information related to various other building installations such as sprinklers, lighting, HVAC (Humidity, Ventilation, Air Conditioning) and CCTV cameras. Ideally this information should also be available for all the potential end-users of the IS proposed. Currently, in most of the large-scale modern buildings, information related to these systems is available via Intelligent Building Systems (IBS) (Kwan and Lee, 2005). This includes the state of art buildings such as the Westfield Derby and the Highcross (Shires) Leicester, which were used as scenario sites for this study. However, use of such information is restricted to the access of the personnel located at the control rooms of such premises since the use of IBS were originally developed for building management purposes. Nevertheless, it can play an important role to support firefighters by acquiring and conveying knowledge about a disaster environment, especially on the fixed installations located within the built environment. Hence, it will be very important that IBS become part of the network of the IS proposed. Currently the most commonly available networking platform for IBSs takes the form of either a Local Area Network (LAN) or a Wireless Local Area Network (WLAN). Therefore, communication between the WSN, which is proposed to capture the contextual data and the WLAN/LAN belonging to the IBS of particular premises, is essential. This will be very much easier since both types of networks belonging to the same premise and the same owner.

Having identified the networks, various available network protocols are compared in Table 7.1 with the aim of selecting the most appropriate for the architecture proposed. It can be seen that the Zigbee protocol is suitable to form the sensor-based networks due to its low power, low cost, considerably high amount of data speeds and its capability of forming ad-hoc networks. Therefore, Zigbee is recommended as one of the better protocols to form the WSN, PAN and BAN of the moving firefighters. Although, Ultra Wide Band (UWB) could be the best option to form the BAN (Dvorak, 2008),

Table 0.1: Comparison of Wireless Network Protocols

| | ZigBee | 802.11 (Wi-Fi) | Bluetooth | UWB (Ultra Wide Band) | Wireless USB | IR Wireless |
|----------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------|---------------------------------------------------------------------------------------------|-----------------------------------------------------------|------------------------------|-----------------------------------------------------|
| Data Rate | 20, 40, and 250 Kbits/s | 11 & 54 Mbits/sec | 1 Mbits/s | 100-500 Mbits/s | 62.5 Kbits/s | 20-40 Kbits/s 115 Kbits/s 4 & 16 Mbits/s |
| Range | 10-100 meters | 50-100 meters | 10 meters | <10 meters | 10 meters | <10 meters (line of sight) |
| Networking Topology | Ad-hoc, peer to peer, star, or mesh | Point to hub | Ad-hoc, very small networks | Point to point | Point to point | Point to point |
| Operating Frequency | 868 MHz (Europe) 900-928 MHz (NA), 2.4 GHz (worldwide) | 2.4 and 5 GHz | 2.4 GHz | 3.1-10.6 GHz | 2.4 GHz | 800-900 nm |
| Complexity (Device and application impact) | Low | High | High | Medium | Low | Low |
| Power Consumption (Battery option and life) | Very low (low power is a design goal) | High | Medium | Low | Low | Low |
| Security | 128 AES plus application layer security | | 64 and 128 bit encryption | | | |
| Other Information | Devices can join an existing network in under 30ms | Device connection requires 3-5 seconds | Device connection requires up to 10 seconds | | | |
| Typical Applications | Industrial control and monitoring, sensor networks, building automation, home control and automation, toys, games | Wireless LAN connectivity, broadband Internet access | Wireless connectivity between devices such as phones, PDA, laptops, headsets | Streaming video, home entertainment applications | PC peripheral connections | Remote controls, PC, PDA, phone, laptop links |

Zigbee is preferred due to its suitability to form multiple networks: BAN, WSN and PAN. As an added advantage, most of the sensor platforms now embed the Zigbee as their network protocol. The use of Zigbee to form the firefighter BAN and PAN together with the WSN will further strengthen the communication reliability of the overall network as all the firefighters will become sensor nodes of the network, and so increase the network redundancy. Furthermore, there is greater potential WSN to form the backbone of the future IBSs. Therefore, in the

future, proposed type of WSNs and most components of the IBS, except the channels that need higher data rates such as for CCTV, could merge into a single network, communicating with a protocol similar to the Zigbee. However, at present, building management networks often run with the support of either Ethernet or Wi-Fi protocols.

The support of sensors and sensor-based networks is essential to form the Networks Layer of the proposed ISA. However, when go through the specifications and characteristics of the above considered popular commercial sensors and sensor-based networks, it is evident that their practical application in the context of fire emergency faces some immediate challenges and barriers.

One of the main practical issues of implementing the above type of sensor network is the cost implications related to pre-installed building sensor networks. Although FRS recognises the support of sensor networks as essential to provide a satisfactory level of support to various fire fighting job roles, according to the most of the fire fighter participated in this study, FRS may not agree to bear the cost of the pre-installed building networks. Although it was accepted that there is a need of devices such as sensors and RFID tags to capture various information, from the FRS point of view, the cost of installation of any such devices should come under the budget of the building or premise owner. However, there is a doubt whether this is a viable option. On a positive note, feedback of the firefighters revealed that the benefits of the sensor-based technologies may have the potential to extend support to provide some useful information to the consumers of the buildings apart from improving fire safety of the building and supporting firefighters. According to firefighters, there is a possibility that sensors suitable of supporting fire fighters could also provide some useful information to maintain operations related to day to day services of the buildings and building maintenance and therefore, have the potential of becoming a part of the Building Management System (BMS). So these benefits may motivate building owners to bear some cost elements. Therefore, fire fighters believe that this is perhaps the only and the most viable option.

In addition, most of the firefighters participated in this study believe that sensor networks may cut down insurance premiums and therefore, could become an attractive option for Owners of the buildings. According to them, insurance companies are very much at a risk of paying back billions of pounds worth fire and other building safety related insurance claims due to the lack of technology support to minimize the damages to the buildings and its occupants. Currently, there is a trend that insurance companies encourage building owners to enhance the support of state-of-art technologies that could increase the safety levels of buildings during a fire by slashing the insurance premiums by significant percentages. For example, very high insurance premium discounts are now offered for buildings installed with automated sprinkler systems controlled by intelligent building management systems. Although this study does not investigate the views of the building owners, the following views captured during the field visit supports the above arguments.

View of one of the Senior Officers responsible for the Safety and Security at the Primary Scenario Site of this Study (Derby Westfield Centre): *Yes I agree with X (One of the safety officers of DFRS) if the sensors that capture various hazard information are easily deployable. Since you don't have to put them inside the walls ... what I meant is that we need to do that during the building construction.....so both FRS and us can coordinate each other and carry out the installation ...I'm sure it is going to be a very good concept. Definitely, it will improve the safety of the buildings You may already know that our fire alarms connected to our BMS... so similarly why not connect these sensors to the same system.... Hopefully, with the improved safety features we may able to cut down our building insurance premiums. This is similar to the case of our sprinklers.Our automatic sprinkler system managed to reduce the premium of our building insurance.....*

View of one of the Curators of a Popular Heritage Site in Derbyshire: *You see if you can attach these sensors onto our valuables and if you can provide the location information, we'll definitely consider purchasing them. I think it can support both us and the FRS. ...It definitely can support our staff during our normal work and I can see it may have some benefits for the visitors as well... you see with this kind of system we may not have to update the location of various items manually within the premises...this is important as time to time we move*

them around. On the other hand, in a fire situation the same information will be very vital for both of us and the fire fighters to coordinate the salvage of vital pieces..... So I guess it is a brilliant idea.

View of the Fire Marshall of X – Manufacturing (Did not like to reveal the Name of the Organization): *Of course one big issue we face in our company is that sometimes we don't know where the chemical cylinders are ... specially the acetylene cylinders... these guys (Fire Fighters) are very scared when it comes to handling acetylene ... they simply don't trust our information on their locations..... I can't blame them because.... although we have all the procedures to keep them in a particular designated location, cylinders often move around the building... there is a really big chance that they are not at the designated location so if we can put these sensors on the cylinders it will be really useful not only for fire fighters... it will be useful for our day to day operations as well.....*

The above discussion clearly explains that marketability and implementation of ISs to provide comprehensive support to FRS during ER in large buildings having high-risk of fire may not be feasible unless sensor networks are capable of providing significant benefits to building Owners to manage various day to day building services. Furthermore, it is evident that realistic implementation of such type of sensor networks may need the indispensable participation of three major stake holders; that is the FRS, the Owners of the buildings and the insurance companies that provide fire related safety insurance for high-risk buildings.

Although the cost of sensor motes and accessories related to popular WSN platforms based on popular networking protocols such as Zigbee has come down considerably, still its cost is considered to be one of the main barriers to make it an attractive option for the end-user. Impact of the cost implications could be severe when consider the large number of sensor motes required to provide the level of support expected by the firefighters. For example, to provide the graphical illustrations like in the mock-up interfaces proposed, to present information on the spread of temperature or any other similar parameter with a satisfactory level of accuracy, a WSN fixed in a particular floor of a building may need the support of a large number of sensors. Therefore, if sensor motes to become a viable and attractive device in the fire emergency context there is an immediate need of

further research to find solutions to reduce their manufacturing costs. The running costs of the sensors could also make WSN an unattractive solution for the clients. Primarily the running cost of sensors is the cost of replacing its power source. This could be a high percentage of the overall cost, when consider the number of sensors required. When it comes to minimizing the running costs and making them commercially viable, it is also vital to conduct further research to reduce the power consumption levels of the sensors so that they can become energy efficient. Currently, this is one of the most active areas in sensor related research. This includes research in energy-scalable algorithms and protocols (Sinha and Chandrakasan, 2001) and alternative power harvesting or scavenging methods (Kompis and Aliwell, 2008) with the support of regenerative sources such as solar power, vibration and wind power to power up the sensors for a longer period. Most of these works are focused on the application domains such as military, aviation, manufacturing and building services (Methley et al., 2008). However, there is very little evidence available whether these researches address the needs of the context discussed in this study. Therefore, the current, progress made in this area of research lag behind the minimum satisfactory levels expected in the fire emergency context.

One other main limitation is the physical size and the weight of the sensor nodes. When consider the application of sensors for the implementation of ISA proposed, currently available physical characteristics of most of the sensors could become a major obstacle. When a WSN is attached to the buildings, it can create implications ranging from physical appearance of the buildings to installation of sensors. In addition, when consider the sensors of the BAN of the firefighters and deployment of sensors carried by firefighters, there could be serious issues related to flexibility of handling them. Although this is an active research area, the progress made so far to obtain the support of the sensors in contexts similar to fire emergency is negligible. Therefore, there is an essential and immediate need to carry out more focused research to improve the physical characteristics of sensors to be used in the conditions applicable for fire emergencies.

Apart from future research to minimize the above limitations, this study proposed to seek the possibility of merging with other low-cost devices and technologies to

form more heterogeneous sensor networks rather than depending on a one particular platform. For example, RFID and WSN based on sensor motes are two important wireless technologies that have a wide variety of applications, which provide unlimited future potentials. RFID technology facilitates detection and identification of objects that are not easily detectable or distinguishable by using current sensor technologies (Liu et al., 2008). The size and weight of RFID tags makes it much easier to handle. In addition, RFID is a very low-cost technology compared to any other ad-hoc sensor mote platforms (Zhang and Wang, 2006). However, it does not provide information about the condition of the objects it detects. In contrast, sensor motes can provide information about the condition of the objects as well as the environment. In addition, operational range of sensor motes is comparatively much bigger than the RFID tags due to its flexible mesh networking ability (Sumi et al, 2009). Hence, integration of these two technologies will expand their overall functionality and capacity. Although RFID is not an actual contextual sensor, it can be proposed to integrate with sensor motes to form a low-cost heterogeneous network. This network will be capable of location tracking and contextual sensing compared to a network, which is exclusively comprised of sensor motes. Hence, from the building owner's point of view, especially for the exclusive purposes of location tracking, the use of RFID could be much cheaper and appropriate compared to a sensor mote. One classical example is to tag artefacts of an art gallery or a museum. Also from the FRS's point of view RFID tags could be much preferred as it is less expensive and easier to handle if firefighters have to carry them. Therefore, it will be very important to consider merging wireless sensors with RFID together in the same network. This proposal can be justified as already there are several previous research attempts such as warehouse tracking (Zhang and Wang, 2006) and patient tracking in hospitals (Bacheldor,2006), which recognized the synergic advantage of Zigbee based wireless sensors and RFID based networks.

Another challenge is whether the sensor nodes can maintain their accuracy in harsh environments and high temperatures with uninterrupted networkability. Currently, none of the commercially available sensors is capable of withstanding the high temperatures expected in a progressive fire. Hence with current capabilities, firefighters may not benefit from the network for long durations. This

will be one of the main challenges faced by the sensor manufacturers in the future. To overcome the above challenges, in relation to this particular study, the following can be proposed to consider as new areas of research.

- Research related to sensor manufacturing is necessary to increase the life time of the sensor nodes so that they can withstand much higher temperatures expected in fire grounds.
- Research is necessary to develop algorithms, which are capable of correcting or adjusting the accuracy of the readings of sensors that deteriorate its sensitivity and accuracy due to harsh environments.
- To a certain level, the profile of the sensor deterioration itself can be used as information to indicate the contextual progress. Hence, it will be useful to investigate such concepts to utilize the services of deteriorating sensor nodes for longer durations in the contexts of fires.

As well as problems related to operating in the extreme environments, there is also a doubt whether the commercially available sensor devices are capable of providing the level of accuracy expected by the firefighters even when they are operated under the normal circumstances. However, as discovered in the evaluation part of this research the accuracy required for a selected piece of information can vary from job role to job role, incident progress and type of operation. Hence, it is evident that appropriate use of sensors could provide considerable support during a fire emergency with their current level of performance. For example, with the current level of performance, sensors are capable of detecting the start of an actual fire. This is identified as early information vital for the firefighters who are first to arrive at the incident. However, this is not true for all the information needs. For example, the level of accuracy of the outcome of previous research such as “LifeNet” (Klann, 2008), Gambardella et al. (2008) and “CADMS” (Walder et al., 2009) do not meet the level of accuracy expected by the frontline firefighters to navigate them during their operations. Thus, there is a need for further research related to improving sensor related algorithms and communication protocols, if they are to reach the accuracy expected for some of the information needs of firefighters.

The selection of Zigbee as a communication protocol is not a surprise or new as some of the previous research such as “Fire” Project (Wilson, 2007)

recommended the use of Zigbee to form the WSN and even to form the BAN of firefighters. However, the lower data rates of Zigbee based sensor devices may create a bottleneck in forming the BAN of firefighters where it may have to embed with devices such as wireless thermal image cameras or HMDs to display higher amount of graphical data. Data speeds required for these possible wearable audio and visual display components of the BAN may require higher data rates within the BAN as well as communicating with other External Servers. For example, although previous similar research such as the “Fire” project proposed the use of HMDs embedded with the devices supported by Zigbee protocol, it is not clear the amount of graphical data handled. The argument is that if this data is to be transmitted from an outside device to the BAN of an individual firefighter then the data rates of Zigbee based devices may not be sufficient. Therefore, it is crucial to find a solution to overcome such constraints. These requirements suggest that some improvements and further research related to the data speed and bandwidth are essential to satisfy the expectations of the end-users. As an initial step towards a solution for Zigbee based networks, this study proposes following options for future consideration.

- Pre-install the relevant map data in a wearable computer attached to the BAN of the moving firefighters and continue with Zigbee to 1) form the BAN communication, 2) communicate with external servers and 3) WSN. Use a protocol such as Bluetooth or UWB to communicate between audio, video devices and the central processing unit (CPU) of the Wearable computer if data speed or bandwidth needs to exceed the capabilities of Zigbee. By processing graphical data locally at the BAN, Zigbee capable motes can be used more effectively to capture various contextual information generated within the BAN (Example: Heart rate and Body temperature of a firefighter). In addition, Zigbee enabled CPU of the wearable computer will be able to communicate with computers outside the BAN and the WSN to acquire contextual and location information. In addition, information storage and processing capability of Zigbee motes may also improve the information processing at the CPU of the BAN.
- To have a BAN, working on the Wi-Fi platform with much higher data rates to communicate with the outside servers via pre-installed wireless routers fixed inside the building or located at the bridgehead. High bandwidth Wi-Fi

protocol allows dynamically transmitting and receiving graphical and contextual data from the outside servers. Therefore, with this option map data can be installed in a server located outside the BAN rather than installed in a device belongs to the BAN. Similar to the previous option, communication within the BAN can be via either Zigbee or combination of Bluetooth/UWB and Zigbee in combination. However, this particular option brings additional challenges of connectivity. For example, with the incident progress, most of the pre-installed routers may fail due to harsh environments.

The above discussion clearly suggests that there is an immediate and essential need of conducting much vigorous research related to the above explained challenges if sensors and sensor-based networks to support fire emergency context satisfactorily.

Networks for Mobile and Semi-Mobile Pervasive Devices and Equipment Deployed at the Incident

It is evident that to acquire useful contextual information upon arrival at the incident premise, it is essential Mobile Data Terminals and other computers fixed inside the fire engines, Command Support (CS) vehicles and other related vehicles such as vehicles driven by the incident commanders to continuously maintain connectivity to the networks 1) located inside the incident premise, 2) nearest FRS control room and 3) some databases located away from the incident premises. It is also important for many other pervasive devices proposed for the use of information presentation of different firefighter jobs like

- BA Boards with wireless connectivity,
- Large Liquid Crystal Displays (LCDs) with wireless connectivity,
- Laptops and PDAs or any other devices used by various SCs, which are possibly located within and outside the building premises

to have similar communication and connectivity needs. Importantly the location of these equipment and devices are not fixed. Often they are either mobile or semi-mobile. So their locations are ad-hoc and could change throughout the ER operations.

It is vital to maintain expected amount of uninterrupted yet cost effective connectivity of various pervasive nodes, which are mobile and requires highly ad-hoc nature of networking. Therefore, this study proposes a Mobile Ad-hoc Network (MANET) to maintain required level of communication and connectivity. A MANET is an autonomous collection of mobile nodes that communicate over the wireless links, which have relatively constrained bandwidth (Subbarao, 2000). Each node is equipped with wireless receivers and transmitters. Since nodes are mobile, the network topology may change rapidly and unpredictably over time. The network is decentralized; where all network activity including discovering the topology and delivering messages must be executed by the nodes themselves. To support an emergency, a MANET may need to be operated in a stand-alone manner, or to be connected to a larger network as required for the type of system proposed in this study to form a Hybrid MANETS (Subbarao, 2000) by connecting many IP based networks.

Although there is hardly any evidence in relation to the application of MANETS directly related to the proposed type of IS, previous research carried out in relation to MANETS has recognized its uses in emergency related domains. Among such previous efforts the following proposals for the use of MANETS are identified as significant.

- The design, implementation and performance evaluation of CHAMELEON, an adaptive Quality of Service (QoS) routing solution, with improved delay and jitter performances, enabling multimedia communication for MANETs in extreme emergency situations such as forest fire and terrorist attacks (Ramrekha and Politis, 2009).
- A project focused on the design of an integrated system, composed of a satellite segment and a MANET, to provide both data and voice telecommunication services in emergency scenarios. This project used a test bed scenario where a certain number of teams belonging to the same command or independently coordinated (i.e. military forces, police, firefighters, rescue teams, etc.), cooperate in the same mission having the following requirements in terms of connectivity: between units of the same team, between units belonging to different teams using different systems or technology or equipment, with a remote station (Luglio et al., 2007).

- Jang et al. (2009) and Lien et al. (2009) looked at the possibility of deploying MANET based Rescue IS for Earthquake Disasters (RISED) to support rescue operations for catastrophic earthquake disasters. This network intends to support the officers in rescue organizations, voluntary or mission specific professionals who use their own notebook PCs to construct a multi-hop ad-hoc network to form a basic intranet as well as get connected with external databases to exchange useful response related information.
- DUMBONET was designed to operate in real physical disaster affected fields. The goal is to provide rescue teams who may simultaneously explore physically isolated disaster fields with mobile ad-hoc multimedia internet communication among field team members and with a distant command headquarter (Kanchanasut et al., 2007). DUMBONET consists of heterogeneous networks having different MANET devices, various link types (i.e. Wi-Fi, satellite and terrestrial) with very different link characteristics (i.e. bandwidth, packet loss pattern and delay)
- A test bed application by Subbarao (2000), which focused on the Network Layer operation of routing and implications of power consumption for emergency MANETs.

These examples illustrate the potential of forming MANETs and integrating them into IP-based systems to enhance the flexibility and pervasiveness of the networks proposed. However, integrating MANETs with the internet gives rise to challenges such as extensions to both Mobile IP and ad-hoc routing protocols. There are many technical issues still remaining unsolved in this field (Ding, 2008). For example, a survey of recent advances in technical issues in connecting MANETs to the internet (Ding, 2008) revealed that previous researchers rarely considered scenarios such as a MANET consisting of roaming nodes and multiple gateways to the internet. The design of protocol interfaces to achieve integration of ad-hoc routing protocols and Mobile IP into the IP routing system of the Internet is identified as one of the most crucial challenges in this area. According to Ding (2008), this has not been effectively addressed by research published thus far. Hence, the success of the proposed type of emergency related systems will significantly depend on the progress of research in linking MANETs with the internet.

To implement the ISA proposed successfully, it is essential that the above proposed MANET to communicate with the WSN or/and IBS installed at the incident premises. To maintain such connectivity, this study identified three feasible means: 1) MANET joining the existing WSN of the building as another node, 2) MANET joining the Wi-Fi network of the building premises directly and 3) MANET forming a link to the building network via the internet to form an indirect link to building networks. Rather than having a single mode of connectivity this study encourages maintaining multiple modes of connectivity as it could increase the network redundancy. Ideally the same information available to the fire engines arrived at the incident premise should be also available to all other fire engines, which are on the way to the incident. Therefore, each fire engine should have a continuous link to the internet. Such a link will not only allow them to communicate with the networks at the incident premise but also with their control room and any other useful databases that become potential information sources. Having considered the mobile nature of the fire engines, four kinds of mobile communication technologies are proposed to form the necessary Wide Area Network (WAN) connection.

- a) GSM/3G/4G/GPRS based public mobile networks
- b) Non GSM Networks such as WiMAX
- c) Proprietary terrestrial trunked radio (TETRA)
- d) Satellite communication

However, different type of mobile networking options has its advantages and drawbacks (Meissner et al., 2006). Digital mobile networks based on GSM, 3G or 4G are becoming quite popular due to its low-cost and higher data rates. Day by day their data rates are getting increased. Hence compared to other technologies, 3G and 4G networking options provide the highest bandwidth at favourable prices with coverage in almost all inhabited areas in many countries (Meissner et al., 2006).

Currently in the UK, data rates in the region of 10Mbps are available for any broadband user. However, their operation is primarily depending on some critical fixed infrastructure such as radio towers and base stations, which are very much vulnerable during large-scale disasters and may be totally disrupted (Protacio,

2009; Meissner et al., 2006). Another issue is that its inability to provide higher priority for emergency communication over non-emergency communication due to its public accessibility (Meissner et al., 2006). Therefore, responders cannot rely solely on such public communication infrastructures in disaster response (Meissner et al., 2006). In contrast, proprietary terrestrial trunked radio technologies such as TETRA is deployed for the exclusive use of public safety organizations (Meissner et al., 2006) because TETRA based networks 1) will not fail during emergencies due to data overload, 2) are available across remote locations and 3) provide enhanced security. Particularly in the UK, TETRA is used by more than 200 organisations, including the police, fire and ambulance services, to support the mission-critical communications involved in public safety (Airwave, 2010). Its main drawback in relation to supporting proposed type of system is its lower data rates. It supports only 28.8 Kbps. data transfer rate and in most cases even less (Meissner et al., 2006). Therefore, there is a doubt whether it is capable of covering the expected level of data transmission required for the type of IS proposed.

To overcome some of the above challenges, emerging networking technology, Worldwide Interoperability for Microwave Access (WiMAX) is recognized as a suitable alternative technology to be considered for further research. Currently, WiMAX is designed to provide 30 to 40 Megabit data rates and it is being seen as a possible substitute to cable modem and DSL services in the future. Importantly, WiMAX technology is successfully used for communication application during recent major disasters. For example, WiMAX was used to assist with communications in Aceh, Indonesia, after the tsunami in December 2004. All communication infrastructures in the area, other than amateur radio, were destroyed, making the survivors unable to communicate with people outside the disaster area and vice versa. WiMAX provided broadband access that helped regenerate communication to and from Aceh. In addition, WiMAX was donated by Intel Corporation to assist the FCC and FEMA in their communication efforts in the areas affected by Hurricane Katrina (Sinha, 2005b). European research project “WEIRD” have been evaluated and defined several emergency related scenarios: Environmental Monitoring, Telemedicine and Fire Prevention that can take advantage from the WiMAX technology (Neves et al., 2007). The above

discussion justifies WiMAX as a Wireless technology to access internet, which is very promising for supporting Emergency Services. However, future of WiMAX deployment for internet access is still in the early stage due to its novelty. Also, it has a major drawback in relation to the use of the electromagnetic spectrum since the WiMAX technology requires a bigger slice of bandwidth at the 3.5GHz band.

As another alternative to form a WAN connection, satellite communication is well-known for its high availability. It has very good outdoor coverage and is not affected by local disasters. Recently, new data oriented satellite services, such as Inmarsat's Regional Broadband Global Area Network (RBGAN) and Inmarsat M4 MPDS (Mobile Packet Data Service), makes mobile satellite communication more attractive for public safety organizations (Meissner et al., 2006). However, satellite communication is more expensive compared to all other technologies mentioned above and needs an unobstructed line-of-sight to the satellite used. Furthermore, for a mobile vehicle such as a fire engine, satellite communication may not provide higher data rates compared to that of a stationary vehicle (Meissner et al., 2006). Hence, it is more suitable for a semi-mobile or stationary vehicle to get connected to internet when other cheaper options of getting connected to the internet fails.

Apart from the above described, it is essential to maintain access between fire engines and various public or proprietary databases, which broadcast information on traffic, weather and media. In addition, it is essential to maintain communication links with other agencies specifically related to emergencies such as the police, the ambulance services, local councils and environmental authorities. This allows proposed IS to have access to personnel data that can be useful to identify most appropriate experts. It also allows recognizing and locating members and experts of other agencies who are already deployed at the incident grounds. It is also important to provide access to the water supplier's database, especially to acquire the dynamic water pressures of the hydrants. All these communication could be maintained via the internet. At present, most of these databases are already connected to the internet via different fixed terrestrial or satellite links. However, there is a greater possibility that access to these databases via the public mobile data networks can be disrupted during emergency

situations. Hence, further investigations would be necessary to identify reliable yet low-cost alternative considering the amount of data exchange necessary. For example, considering the fact that most of the emergency services are now connected to the proprietary networks such as TETRA, as a low-cost alternative it would be useful to check the feasibility of TETRA networks to connect at least the emergency services.

Networks between Incident Premise and the FRS Control Room

At present, in the UK an automatic fire alarm rings at the control room of the FRS when fire emergency occurs at the highest risk buildings. However, it was identified that it is much better if the control room can have constant access to the WSN and/or IBS located at the incident premises. This type of link should be continuously maintained for all the high-risk premises irrespective of the incident. These requirements of the FRS suggest that it will be crucial for the networks capturing contextual information at the incident premise to communicate continuously with the nearest control room of the FRS. The following means of communication are proposed to facilitate the above identified requirements.

Essentially, networks at the building premise should have a link to the internet cloud either via fixed terrestrial link such as DSL/ADSL or Fibre optic. But compared to these terrestrial networks, non-terrestrial satellite links may provide more reliable connectivity to the internet. However, very high cost for satellite communication could become a major limitation for its use. In emergency situations, non terrestrial connectivity is recommended at least as a backup channel at the control room to get connected to the internet. Each control room of the FRS should also have a similar link to the internet. Hence, by forming Internet Protocol (IP) based Virtual Private Network (VPN) across the internet, an incident premise could be easily and continuously connected to the nearest FRS control room. Alternatively, there is an option of maintaining a point to point communication link via dedicated ADSL/DSL, Fibre optic or Satellite link. The “FiReControl” project states that some of the large-scale high-risk buildings in the UK are considering the option of having a direct data link to the nearest Regional Control Centres (RCCs). Since system proposed in this study is exclusively for some selected high-risk premises, in the future there is a greater possibility of

maintaining point to point communication links between the premise of the incident and the FRS control room. The identified requirements of firefighters clearly indicate the need of having constant communication between the FRS control rooms and fire stations for appropriate mobilization of resources. These networks could be formed via the internet with the support of fixed terrestrial links or satellite links. Also as a suitable alternative it may be important to consider proprietary terrestrial option such as TETRA.

It is crucial to maintain adequate privacy and security among all possible combination of network nodes. Hence, as any other secure network, these links can take the form of a *Secure VPN*, which uses cryptographic tunnelling protocols such as Internet Protocol Security (IPSec) to provide the required confidentiality (blocking intercept and thus packet sniffing), sender authentication (blocking identity spoofing), and message integrity (blocking message alteration) to achieve privacy. It is equally important that the heterogeneous environment must not only be hidden from end-users, but also be made transparent to applications (Cavalcanti and Dharma, 2005). A VPN may also be important in this regard as it can hide the heterogeneity that arises from the use of different wired/wireless networking technologies and communication technologies such as satellite or any other wired/wireless terrestrial networks (Kanchanasut et al., 2007).

Appendix 7.2: Technology Concept Suitable for Deployment of the HCI Modules of the Proposed ISA

HCI Technology for ICs and Operation Commanders

During the mock-up evaluation session, it was confirmed that it is appropriate for IC to use a large display device to access visual information as well as an ear mounted speaker for necessary audio information such as alerts and alarms. End-users preferred both touch screen capability and the digital stylus to interact with the visual interfaces deployed onto large visual displays. During the field work of this study, it was revealed that some of the brigades of the UK FRS have already adopted some established technologies related to large visual displays and improved audio devices. Members of the IC teams are satisfied with such technologies and are very much comfortable using them. Currently these brigades use various products consisting of following specifications:

- LCD and Plasma display devices ranging from the sizes of 32”- 50.”
- Embedded with Touch Screen Capability including stylus devices for easy data input.
- Capable of communicating via various wireless protocols such as Wi-Fi, Bluetooth.

One of the favourite technologies among several local fire brigades is to use either LCD or Plasma touch screen overlays to convert normal large LCD or Plasma display to make it touch screen capable. Recently, optical sensing and infrared overlays are becoming more attractive technology for multi- touch sensing (U-Touch, 2009). Currently, in the market there is a variety of headsets with both microphone and speaker. These headsets are able to work in various communication platforms such as Bluetooth and RF. Field work during this study has revealed attempts of some of the fire brigades to adopt RF based wireless headsets developed by “Firecom” (2009). Although they are expensive, most of the end-users are very much satisfied with the performance of these technologies.

The above discussion clearly indicates that practically, it is very much feasible to implement the proposed HCI Module for IC & Operations Commanders with the support of the currently available technologies. Therefore, these technologies can

be recommended for any future attempt of developing an IS for the support of IC and Operations Commanders.

HCI Technology for SC Commanders

During the mock-up evaluation, it was confirmed that a device similar to a laptop, which can withstand in tough environmental conditions is the most feasible to deploy the visual interfaces. It is also necessary to have a device similar to that proposed for ICs to deploy some crucial audio driven information. Furthermore, as explained above, for the crew commanders and safety officers, a similar type of information presentation devices is proposed. With the technology upgrade proposed in the “New Dimension,” some of the brigades of the UK FRS are currently running some pilot projects to test the feasibility of rugged laptops for the use of commanders specially when they carry out operational activities and on the way to the incident premises. For example, *Panasonic Toughbook* (Toughbook, 2009a) that comes in the form of a lap top as well as in the form of a tablet PC is identified as one of the popular brands across many of the UK emergency services (Toughbook, 2009b). It can withstand harsh environments for longer duration with its built-in batteries. Field work of this study revealed that almost all the emergency services in the East Midlands region, police, fire and ambulance services use the *Toughbooks* on and off the field. In Leicestershire and Derbyshire FRS, *Toughbook* are already deployed for the use of CS teams and most of the end-users are satisfied with the user friendly touch screen capable displays.

Apart from the above, many other popular manufacturers have developed rugged laptops and tablet PCs with touch screen capability exclusively for the use of emergency services. Currently, it is a proven mature technology and most of the available products are mature enough in toughness and robustness. However, several key elements, which need further improvement, are identified in relation to the deployment of the type of system proposed in this study; 1) processing speeds 2) interoperability and compatibility of operating software 3) user friendliness and 4) cost. It is evident that more and more touch screen based products are becoming popular in the consumer markets. Hence, much smarter and user friendly touch screen based computers such as *HP Touchsmart* (HP

Touchsmart, 2009) multi-touch capable laptops are becoming quite popular and affordable in the consumer markets. Their popularity may increase as operating systems such as *Windows 7* exclusively support the touch screen based computers. Such developments clearly indicate the possible enhancements in the speeds, user friendliness, compatibility and the affordability in relation to the touch screen based computers.

HCI Technology for BAECOs

During the mock-up evaluation, it was confirmed that the BAECO need the support of human computer interfaces deployed onto a large visual display resembling the size of current BA Entry Control Board and suitable audio devices similar to the devices proposed for ICs and SCs. Semi-automated Dragger PSS Merlin is the most advanced technology used as the BA Board in the UK FRS at present. This particular BA Board lacks the information visualization, storage, processing and communication capabilities required to deploy the BAECO module as proposed in this study. Hence, to populate the proposed visual information, it is essential to use a large display device embedded with high-level processing ability and heterogeneous networking capability.

Investigation into the proven and mature technologies only identified a single product, namely the *HP Touchsmart* as suitable. *HP Touchsmart* is a Computer with the multi-touch capability. It comes in a range of computers from laptops to Large Display PCs (HP Touchsmart, 2009). Some of its models take the form of a large tablet PC where processing unit and display unit is embedded inside the large display. Currently, there is hardly any evidence available on any other PC that comes as a single unit and can offer touch screen capable LCD as large as that of the *HP Touchsmart*. In addition, its processing, storage and networking capability remains par with any other high performance PC. Its capabilities and compatibility as a multi-touch system is further enhanced with the introduction of *Windows 7* operating system. Although *HP Touchsmart* is a fully fledged touch screen based PC with a large display, it has the following constraints in relation to deploying BAECO application component proposed.

- It is not designed to work with built-in batteries. This would be a major drawback when it comes to a device suitable for deploying BAECO

module.

- Toughness and Durability of the product is below the actual requirement.
- It is heavier compared to Dragger PSS Merlin type of a BA Board.

Therefore, successful deployment of the proposed BAECO interfaces will become a challenge with currently available technologies. There is a gap in technology to deploy information onto large displays for longer durations operating in harsh environments. Further research should be carried out to develop a better product, which consist of a large display, embedded with high-end processing, storage, connectivity and can run in isolation from built-in batteries away from the AC mains.

One promising line of research, the “Sixth Sense” (Mistry et al., 2009), which is conducted by the fluid interfaces group of the MIT media lab, is identified as a suitable technology to build display device for a BAECO. The “Sixth Sense” project proposes a wearable device embedded with a tiny projector to project information onto surfaces, walls, and physical objects around. Furthermore, it lets the user interact with the projected information through natural hand gestures, arm movements, or interaction with the object itself (Mistry et al., 2009). Hence, it may be possible to combine the ubiquitous concept promoted in the “Sixth Sense” project with a computer similar to the *Panasonic Toughbook* (Toughbook, 2009a). As described earlier, this type of computers can withstand harsh environments for longer duration with built-in DC power. Therefore, with the processing capability of *Panasonic Toughbook* type computer the “Sixth Sense” type of ubiquitous concept will be able to project and interact with BAECO related information on to a wall of the incident building or simply onto any available surface. Such type of product could cope with the challenges of presenting BAECO related information in extreme environments, isolated from AC power mains where large computer displays such as *HP Touch Smart* type of displays are not feasible to operate.

HCI Technology for BA Wearers

Successful deployment of the human computer interfaces for BA Wearer is considered the most challenging among all other components. As proposed in Chapter 5, the technological platform must be capable of combining visual and

audio mediums while interaction with the display device should be predominantly via the medium of voice. Currently in the UK, the only technology that is used by moving firefighters for visual imagery is the wireless thermal image camera. In addition, there are some pilot projects to use throat operated microphones to replace conventional two way devices. Several projects such as “Fire” project (Wilson et al., 2005) have proposed the use of a HMD for firefighters moving. Yet, there is no evidence that HMDs are being used and accepted as a proven technology suitable for the use of firefighters moving. Although throat operated microphones are identified as suitable to replace traditional radio devices, there is no evidence of using them to either control or combine them with any type of visual display to deliver information for a moving firefighter.

“Drishti” (Helal et al., 2001; Ran et al., 2004) is one of the handfuls of solutions that resemble some of the features required for the implementation of the solution proposed for frontline firefighters. “Drishti” is an Integrated Indoor/Outdoor Navigation System for Visually Impaired and Disabled people. It uses voice commands for navigational instruction. Importantly “Drishti” is embedded with a voice recognition engine and thereby allows users to control the device with their voice. Therefore, work such as “Drishti” can contribute to find a solution to aid navigation of a moving firefighter by reducing the visual overloading of firefighters and providing hands free and eyes free interaction with the use of alternative technologies. Apart from work such as “Drishti,” there is a very little evidence found where voice is being used in combination with visual devices or using it as a display controlling mechanism in relation to moving personnel in harsh environments. However, in isolation 1) there are commercially available products capable of deploying both visual and voice based information on to a helmet mounted devices 2) throat operated microphones being used by moving operators and 3) voice recognition is commercially used to control devices in the domains such as military, aviation, transportation and home entertainment.

Therefore, having considered the unique characteristics such as incident ground noise, mobility, hands free and eyes free nature in relation to a moving firefighter there is a significant technological gap in what is available and what is required. Consequently, there is a greater need for further research related to the use of

voice and visual technologies together to produce a suitable device to deploy the human computer interfaces supporting moving firefighters.

HCI Technology for CS Officers

As explained in Chapter 5, the new Enhanced CS vehicles introduced to the UK FRS are embedded with the state of the art technologies such as large format touch screens (both inside and outside the vehicle), ruggedized tablet PCs linked to the CS computers, computers with enhanced processing speeds. All the computer equipments installed in these vehicles are Wi-Fi enabled. These vehicles are provided high bandwidth connectivity to the internet, and some of them are capable of receiving streamed imagery from Unmanned Aerial Vehicles (UAVs). These vehicles are capable of becoming mobile command and control units for the future emergencies. Therefore, these technologies are ideally suited to deploy the application component of CS officers to support the IC team.

HCI Technology for Officers at the Control Rooms

Based on the lessons learnt in the mock-up evaluation, it will be useful for the officers at the control room to have access to some of the interfaces similar to that proposed for the IC job role. This enables them to make timely decisions on confirming a fire incident and deploying the necessary resources rapidly. Hence this particular application component should consist of interfaces similar to that of the IC. The Regional Control Centres (RCCs) proposed under the “FiReControl” program scheduled to be fully operational from the year 2012, will comprise of state of the art Command, Control, Communication, Computing and Information (C4I) technologies. The C4I technologies include touch screen based operator terminals and large wall-mounted display screen that will show a wide range of information such as maps, the location of appliances and images from the scene of an incident (East Midlands Fire and Rescue Control Centre Ltd., 2010). These C4I technologies will be an ideal platform to deploy the system components that support officers at the control rooms.

HCI Technology for Fire Fighters on Route to an Incident

During the development of mock-up interfaces, it was decided that mobile data terminals fixed inside the fire engines and state of art new generation laptops are

appropriate to deploy the interfaces for the use of firefighters on-route to an incident. As explained in Chapter 6, end-user feedback during the mock-up evaluation firmly confirmed the use of the above devices as appropriate. Therefore, mobile data terminals already deployed under the “FireLink” project is recommended to deploy the interfaces for the use of firefighters on route the incident. In fact, a device such as *Panasonic Toughbook* type laptop, embedded with the touch screen capable visual display is recommended as more suitable compared to the traditional mobile data terminal, which is permanently fixed at the front dashboard of the vehicles.