Evaluation of a Software Prototype for Supporting Fire Emergency Response

Raj Prasanna
Loughborough University, United Kingdom
bsrpr2@lboro.ac.uk

Lili Yang
Loughborough University, United Kingdom
l.yang@lboro.ac.uk

Malcolm King
Loughborough University, United Kingdom
m.king@lboro.ac.uk

ABSTRACT

Despite recent work on information systems, many first responders in the UK Fire and Rescue Services (FRSs) are unable to develop sufficient understanding of the situation to enable them to make good decisions. As a partial requirement of the development of information system for the UK fire and rescue services, a software prototype consisting of a number of human computer interfaces are developed and subsequently evaluated to explore how to present useful information for firefighters during their response operations. This paper exclusively discusses the findings arising from end-user demonstration sessions conducted via participative type of prototype evaluation which is aimed to understand the appropriateness and usefulness of the proposed software prototype. This paper contributes to improve the designing of the human computer interfaces and human computer interaction for supporting fire fighters during fire emergency response.

Keywords

Emergency response (ER), situation awareness (SA), fire and rescue, software prototype, human computer interface, human computer interaction (HCI)

INTRODUCTION

Essentially, ER information systems should support first responders by enhancing their Situation Awareness (SA) leading to better decision-making (Klann et al., 2008). It is argued that human decision-making failures during the catastrophic incidents such as Bhopal (Endsley, 1999), firefighter deaths during 9/11 (Son et al., 2007) and Three Mile nuclear meltdown (Itoh and Inagaki, 1997) are caused by the SA failures of the systems used by the human operators. Key studies that recommend Information System (IS) models and architectures suitable for Emergency Response (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). Most of the SA related 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. Therefore, maintaining a high-level of SA is essential for effective decision-making. Further, this SA related work indicates that designing systems to assist individuals to develop and maintain SA facilitates their decision-making activities (Endsley and Connors, 2008).

Consequently, in a previously conducted study authors of this paper developed and used a cognitive task analysis tool, Goal Directed Information Analysis (GDIA) (Prasanna et al., 2009) to explore and identify information requirements that will lead to better SA of different firefighter job roles during response operations. However, during time-critical, complex situations such as emergencies, the way in which information is presented to the operator through interfaces influences their SA. It is determined by 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). However, most of the previous studies related to supporting ER operations are predominantly interested in generating and coordination of information. There is very little work focused on the presentation of information to enhance SA of the responders.

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The record of the UK FRS is particularly poor in terms of providing the information systems support to the fire fighters' SA during their work. Thus with the aim of supporting fire fighters in the UK to enhance their SA during their response work, authors of this paper made a further effort to explore the presentation and sharing of information to firefighters belonging to specific job roles. First, to explore how to present useful information for firefighters during their response operations, a software prototype consisting of a number of human computer interfaces is developed (Prasanna et al., 2008, Yang et al., 2009). Adhering to the specific design decisions exclusively suitable for fire ER , these interfaces aim to provide the SA requirements of four important fire fighter job roles namely: Incident Commander, Sector Commander, Breathing Apparatus entry Control Officer, Breathing Apparatus Wearer at three increasing levels of knowledge (Endsely et al., 2003b): Level1SA: Perception, Level2SA: Comprehension and Level3SA: Projection. Thus prototypes proposed consist of several categories of information output interfaces.

Interfaces for Level1 SA – Perception

The first step in achieving SA is to perceive the status, attributes, and dynamics of relevant elements in the environment. Lack of basic perception on important information can easily lead to form an inaccurate picture of the situation. 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 (Yang et al., 2009). Thus, as shown in the Figure 1, with this type of interfaces, firefighters will be able to have a high-level summarised overview of the situation.

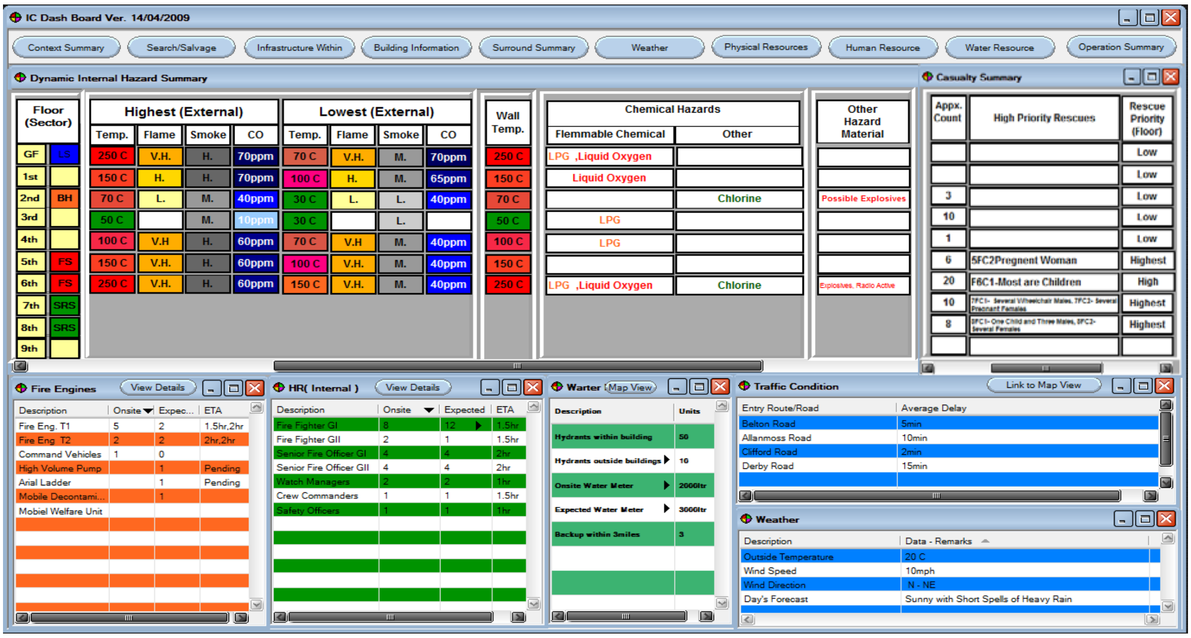

Figure 1: Interface Supporting Level 1 SA of an Incident Commander: "Dash Board"

Interfaces for Level 2 S A – Comprehension

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. It provides the appropriate level of comprehension of the situation at any given moment of time to further improve the SA.

Interfaces for Level 3 SA – Projection

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. Together with the summarised information interfaces enhancing the perception and the interfaces capable of enhancing comprehension of the firefighters. These interfaces are capable of providing a higher-level of SA in making difficult predictions with confidence at any given moment of time of the emergency.

In addition to the above, there are also some other interfaces, which are unique and difficult to categorize. Apart from the information output interfaces, prototypes proposed also consist of appropriate interfaces for Data/Information Input and Alarm/Alert generation. Nearly 350 different information interfaces are proposed for the use of four firefighter job roles. These are designed and developed with the support of Windows-based software prototyping tools, GUI Design Studio Ver. 2 and Adobe Flash. The proposed interfaces form the basis of the first step of an evolutionary development program of a fully-fledged IS supporting firefighters during their response. These interfaces are primarily capable of showing the static situations of a dynamic and moving incident. High-level functionality is introduced with the support of Adobe flash software prototyping tool. Adobe flash software prototyping tool is used for the design of interfaces with some high level functionality; simulating the movement of fire fighters in a building, data entry interfaces embedded with direct manipulation and dynamically appearing alarms. Since it is impractical and difficult to explain the features and functionality of each of the interfaces comprehensively, the following sections which explain the features and functionality of several selected interfaces will provide an overview and the flavour of the interfaces proposed.

The design and development of the software prototype is followed by a series of prototype demonstration sessions with the potential end-users of the system to understand the appropriateness and usefulness of the proposed software prototype for supporting fire ER.

With the aim of contributing to design and development of an information system consisting of usable HCI supporting firefighters during ER, remaining sections, of the paper focuses on discussing the outcome of the prototype demonstration sessions and organised as follows. At first, this paper explains the methodology for conducting the prototype evaluation, including the adopted prototype evaluation methods, method of eliciting relevant and useful participant feedback and analysis, and method of sampling. Thereafter paper discusses the findings of the prototype evaluation, elaborating details of several selected important findings. Finally, the contribution and the conclusions of the study are explained in a summarised manner.

METHODOLOGY

Demonstration of the software prototype is consisted of two, less formal participatory type prototype evaluation phases, Prototype Walkthrough Session (Nielsen, 1993) followed by a Workshop Session (Fitter et al., 1991). A guideline consisting of several hypothetical scenarios is used to maintain the consistency of conducting the Walkthrough sessions. During the Workshop sessions, participants are requested to use the prototype on their own to carry out the hypothetical tasks described. During these sessions, participants are encouraged to ask questions and comment on any of the interfaces proposed. After the two phases of each demonstration, a discussion session is held to obtain some in-depth feedback in relation to the performance of the human computer interfaces. This is supported by a simple discussion guideline consisted of several open-ended questions. Thereafter, the captured pieces of information relevant to each demonstration session are transcribed. The constant comparison technique (Boeije, 2002) is used to identify the fragments of the transcripts, which address some meaningful remarks or comments related to a common theme, discussing an issue or subject suitable of evaluating or improving the performance of the human computer interfaces proposed for each prototype or the overall design and development of an IS for fire ER in general. These fragments are captured from the descriptions of different participants of a single evaluation session and from the participants of several different evaluation sessions. Later, the feedback captured in the form of transcript fragments under various themes is used to extract important findings in relation to the efforts of presenting information to the firefighters.

A mix of Qualitative Sampling techniques: “Homogeneous Sampling” (Patton, 2002), “Snowball Sampling” (Patton, 2002) and “Theoretical Sampling” (Strauss and Corbin, 2008) are adopted for the selection of participants. Participants for the demonstration sessions are selected to cover the target population of the end-users. To improve the richness of the feedback, participation of third party experts representing the FRS and other fire related organizations are also included. Participants selected for the evaluations are as follows:

1. Four Subject Matter Experts (SMEs) already familiar with the study and capable in both Incident Commander (IC) and Sector Commander (SC) job roles (Four Sessions).
2. Four SMEs already familiar with the study and capable in both Breathing Apparatus Entry Control Officer (BAECO) and BA Wearer job roles (Four Sessions).
3. Three Groups consisting of fifteen senior managers capable of providing the feedback for the job roles of both IC and SC (Three Sessions).
4. Three Groups consisting of eleven BA Training Staff capable of providing the feedback for the job roles of both BAECO and BA Wearer (Three Sessions).

These participants are drawn from the FRS brigades of Derbyshire, Leicestershire, and Nottinghamshire counties of the UK. In addition, the Command Support (CS) teams of the two counties Leicestershire and Derbyshire are also selected as participants for the evaluations of IC and SC prototypes. This selection is made on their active participation in the process of information management in relation to the IC team. Halfway through the demonstration sessions it is 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 are added because it became 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 are also selected as the participants. This team is expected to provide some useful independent third party feedback for all four prototypes developed.

FINDINGS FROM THE DEMONSTRATION OF PROTOTYPES

The participant feedback is analyzed in various themes for evaluating or improving the performance of the proposed system. Careful investigation of emerging themes generated by the evaluation feedback led to findings related to the following topics:

- Relevance and impact of the SA failures related to the design of an information system for fire ER. Endsley et al. (2003b) identified eight possible factors that lead to SA failures and named them as SA Demons.
- Overall appropriateness and usefulness of the interfaces to the presentation of information for different fire fighter jobs.
- 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

Among many of the findings related to the above topics the following sections of the paper explains the details of some of the selected findings related to the themes categorised under the first two topics which could become vital in the design and development process of information system supporting fire ER. Importantly, it should be noted that all the findings discussed in this paper are confirmed by the feedback of more than 50% of the individual participants and more than 75% of the participant groups.

Relevance and the impact of the SA demons related to the design of the system

Understanding the impact of SA Demons and efforts of minimizing such impacts in the process of design and development of a system is important (Endsley et al, 2003b). Since this study is primarily aimed to enhance the SA of various firefighter job roles, it is decided to investigate possible SA failures specifically in relation to the design of an IS for fire ER. Thus this investigation is 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 in the proposed interfaces.

Information overload

The way data is processed, stored and displayed to the users can contribute to information overload. Organization and presentation are key elements affecting how well a user can absorb and process data. The feedback 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 to acquire 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 prototypes. For example, rather than having several non-integrated pictures of a situation, one graphical picture, as in the prototypes 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.

Work related stressors

Psychological and physical stressors related to work may negatively affect information intake by making it less systematic and more error prone. The feedback received 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*:* (1)*"Black Box,"* a prototype design concept which is capable of organizing and displaying information in useful and comprehensive manner increasing the end-user awareness on the past events occurred at the incident ground, (2) *"Dash Board,"* a prototype design concept which is capable of enhancing the SA of ICs covering the entire context of the incident ground, (3)*"BA Board"*, a prototype design concept which is capable of enhancing the SA of BAECO covering the entire context of BA related operations and (4) *Incident and Operations Related Alarms*, are 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 *fire fighter relief management* because 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. For a senior officer, who is expecting a promotion and working with his immediate supervisor is 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.

Attention tunnelling

Users fix their attention only on specific elements of information while becoming blinded to other elements. In many situations, users 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. Attention tunnelling is identified as one of the major causes for decision-making failures among all the members of the firefighter hierarchy. Indirectly, it may affect the safety of any person on the incident ground. To avoid attention tunnelling, participants indicated 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 an 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 are 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.

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. The feedback received 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, failure to do so may lead to a situation where the IS will present all the information at once. Failure 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 is 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 may cause such failures. Interpretation mismatch of text and abbreviations are 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 prototypes 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 to them and just ignore them. Therefore, if alarms are to be used to highlight the salience of a situation they must only be used 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, leading 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. Failure of ISs to recognize such differences in salience when presenting the information may hinder the end-users SA rather than promoting it.

System complexities

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. The feedback 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 is also highlighted. Thus, maintaining an appropriate balance is essential. Simultaneously, it is learnt that inconsistent use of colours, symbols and notations may bring unwanted complexity to the interfaces. It is 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 means that officers may need less time to get familiarize to a system module that support their new job role. Therefore, reducing system complexity can lead to a reduction in the cost and the time of organizing systems training 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.

Out of the loops syndrome

Too much automation can push the user out-of-the-loop. Highly automated systems could actually remove the user so far from the elements he or she is trying to control and the user can actually lose touch with the status of those elements. Findings of this study confirm that too much automation can take the end-users out of the loop of SA and the decision-making cycle. 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. 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 is to automate routine jobs, which may consume time. Jobs such as calculating “Time of Whistle,” “Turnaround Time” and identifying firefighters who need *relief* are identified as examples. In brief, 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.

Limited working memory

Short-term (working) memory is often heavily utilized by users to store, assemble and organize chunks of information. 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 could inadvertently cause a larger number of errors. It is evident that firefighters have to remember many things in their working memory and have to process them rapidly to make decisions. New information is generated rapidly during a fire response operation. However, human decision-making takes place at a comparatively lesser speed. Most of the participants felt they often had too much to remember, which inevitably lead to a working memory bottleneck and lose or forget some of the vital information. It is 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 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 is 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 means 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 is 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.

Failures due to inappropriate 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 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. It is evident 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. Use of non-standardized measuring units that differ from FRSs standards may unconsciously 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 is 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, the above 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.

Appropriateness and usefulness of the interfaces

This section explains the detail findings related to the themes describing appropriateness and usefulness of human computer interfaces in supporting decision-making during fire ER operations.

Usefulness of information output interfaces

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 of the incident are more useful for various functional and operational SCs. The simple and quick combination of graphical information layers to deliver comprehensive decision-making support is 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 only to the system generated information. It is also commented that, as proposed in prototype interfaces, it is crucial to provide quick access and rapid navigation between interfaces containing summarised information and 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 prototype interfaces proposed. According to the participants, 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. Thus it 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. Accordingly, these interfaces can provide extra flexibility for the IC team to carry out their operational activities. Participants in the BAECO and BA Wearer prototype demonstrations sessions also indicated their positive response towards the prototypes 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 venue of the incident. This would be an important 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. The feedback also suggested that the interfaces proposed for BAECO and BA Wearer prototypes 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.

Usefulness of appropriate alarms

The BA Wearer's feedback revealed the usefulness of the proposed alarms may lead to successful decision-making in an incident. It is 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 the ICs, SCs and BAECOs also indicated the importance of appropriate alarms. It is 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 occurring at the venue of the incident. According to BAECOs feedback, alarms can reduce work pressure in situations when they have to deploy many numbers of BA Wearers from a single BA Entry Control 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 also work with many competing goals within a very short period. This leaves the firefighter 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 to 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.

Usefulness of appropriate data input interfaces

Most of the participants 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, 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.

The above Participant feedback related to the Appropriateness and usefulness of the interfaces 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) recognized the necessity of SA to become successful in naturalistic decision-making process such as Recognition-Primed Decision (RPD) (Klein, 1993) practiced 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 specifically related to the theme *Usefulness of information output interfaces*, 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. This study also managed to discuss and explain series of important themes related to the remaining prototype evaluation topics on the presentation of useful information for supporting different types of fire fighters. These findings supported for assessing the capability of the proposed human computer interfaces in displaying or delivering information to enhance SA. The outcome of the findings also acted as useful means of re-validating and improving the specification of the previously elicited information requirements. Importantly these findings provided the opportunity for identifying user preferences and perceptions related to the interface design considerations made in the prototype development phase of the study, including considerations related to the devices feasible for deploying the interfaces proposed.

CONCLUSIONS

Although there are several studies which recognize the importance of SA in the process of decision-making, so far there is little significant SA related work done in the domain of fire emergency (Yang et al., 2009b). This study has developed a prototype containing many interfaces and then considered the relevance of SA Demons and their impact in relation to the system for presenting information to firefighters in order to enhance their SA during fire ER. The appropriateness, usefulness of the human computer interfaces proposed have been comprehensively evaluated in this research by going through prototype walkthrough session and a workshop session. The findings from the study are some specific strengths and weaknesses of the interfaces proposed in the four software prototypes. Based on the end-user feedback, necessary modifications to overcome identified design limitations and some recommendations to further enhance the strengths already embedded in the interfaces are proposed. The findings related to the prototype evaluation contribute to the design and development of ISs that support firefighters during their ER operations. Together with the prototype and its interfaces, findings during the evaluation of the prototypes and further enhancements proposed will provide an ideal platform for designers and developers who face the challenge of developing similar ISs. The detailed findings related to each theme presented in this paper add value to the knowledge of previous studies on the 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. The findings presented in this paper do not only focus on one specific technology or a few specific needs, but cover a much wider scope of issues related to presenting information to firefighters.

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