# Developing A Spatial Interface For Information Visualization And Management In A Crisis Response Scenario

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# DEVELOPING A SPATIAL INTERFACE FOR INFORMATION VISUALIZATION AND MANAGEMENT IN A CRISIS RESPONSE SCENARIO

by

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## ABSTRACT

The focus of this study was to investigate how a spatial interface can be effectively utilized to support information presentation and information integration via human-centric data visualization, leading to decreased cognitive load, more accurate situation awareness, and subsequently, improved task performance. In high tempo, information intensive environments like those managed by an emergency operations center (EOC), information organization tools are essential. Though users can be trained to use conventional email software applications efficiently, the constraints of the information management paradigms inherent to conventional systems may limit a user's ability to gather context and create an accurate picture of the situation. It is possible that new data visualization techniques and information management paradigms may improve a user's performance far beyond these limits. To address these issues, theories regarding information management, cognitive workload and data visualization paradigms were explored and applied to create a software prototype spatial interface. This study focused on how an individual member of an EOC would need to collect and organize incoming incident reports (e.g., emails) for the purpose of quick analysis and integration. The operator then used this information to build a picture of the event or events taking place in their sphere of influence. Performance metrics were applied to determine whether or not an individual could perform faster and more accurately with the Incident Report Visual Organizer (IRVO) prototype software interface as opposed to a conventional interface (Microsoft Outlook). The findings from this exploratory evaluation are discussed, as well as the potential implications of utilizing spatial interfaces to manage information in dynamic environments.

This Thesis is dedicated to all those who suffered or died in the wake of Hurricane Katrina.

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# 1.0 INTRODUCTION

The focus of this study is to investigate how a spatial interface can be effectively utilized to support information presentation and information integration via human-centric data visualization, leading to decreased cognitive load, more accurate situation awareness, and subsequently, improved task performance.

## 1.1 Overview

In emergency operations centers (EOCs), operators are challenged with collecting and analyzing massive amounts of information in a timely manner. This information flows into an EOC in a variety of forms: telephone calls, radio, faxes, emails, etc. Teams of people may be assigned to collect, collate and transpose this information into a meaningful picture of the crisis situation. If the picture is accurate and timely, the operators may then interpret the information and make the proper decisions.

In high tempo, information intensive environments like those managed by an EOC, information organization tools are essential. For the sake of simplicity, this study will focus on how an individual member of an EOC would need to collect and organize incoming incident reports (e.g., emails) for the purpose of quick analysis and integration. The operator may then use this information to build a picture of the event or events taking place in their sphere of influence.

Currently, in this scenario, an operator will use conventional email management software such as Microsoft (MS) Outlook. The information management paradigms in programs such as MS Outlook are fairly standard for WIMP-based (Windows, Icons, Menus, & Pointers) interfaces. The user (operator) simply organizes email by color coding it and/or placing it into folders—if they even bother to organize it at all. The user may then retrieve specific emails by searching through the folders or by using a search algorithm that can locate emails based on attributes such as: sender's name, addressee's name, the subject of the email, etc.

Though users can be trained to use conventional email software applications efficiently, the constraints of the information management paradigms inherent to conventional systems may limit a user's ability to gather context and create an accurate picture of the situation. It is possible that new data visualization techniques, information management paradigms and next-generation hardware may improve a user's performance far beyond these limits.

## 1.2 Theoretical Background

To achieve the goal of this experiment, a prototype software program was created based on theory and prior art. It was envisioned that the experiment would reveal whether or not properly applied spatial organization and information visualization theories would decrease operators' cognitive load resulting in a decrease in demand on attention resources, which, in turn, would lead to improved situation awareness and task performance.

### 1.2.1 Spatial organization in Everyday Life

Before exploring how information organization software may be improved, it is worth exploring how humans organize information without automation.

If an EOC operator were in charge of analyzing physical versions of documents (e.g., faxes), how would he or she organize them? Initially, the documents would come out of the fax machine and probably be placed on a desk before the operator. As the number of faxes increased, along with the diversity of information they contained, the operator's first instinct would probably be to spread the papers out across a table. This action, referred to by Kirsh (1995) as "spatially decomposing a task" (p. 44), is an initial effort to organize the information without the benefit of context. As Aaltonen and Leikoinen (2006) observed, "many of our structuring actions serve to reduce the descriptive complexity of our environments" (p. 65). The operator's instinctive step, therefore, can be viewed as an initial effort to use objects in the environment to simplify the task of organization until a more efficient method can be devised. As the operator learns more about the relationships between different documents, piles will inevitably form. Malone (1983) poses four reasons for the creation of such paper piles: "(1) the mechanical difficulty of creating labeled file folders, binders and so forth, especially if multiple levels of classification are desired, (2) the cognitive difficulty of creating appropriate categories and deciding how to classify information in a way that will be easily retrievable, (3) the desire to be reminded of tasks to be done, (4) the desire to have frequently used information easily accessible" (p. 111).

In other words, when confronted with disordered information, humans utilize skills and techniques to decrease cognitive load by first organizing it at a high level—in this case, spatially. This higher-level organization usually results in a loose, generalized set of clusters (e.g., individual piles of papers), which form a starting point for further analysis (Kirsh, 1995). The next step is to analyze the characteristics of each object, noting both unique and common attributes. An iterative process follows where clusters are reorganized, eliminated or parsed down to smaller clusters. During the organization process and any associated tasks upon which the organization effort depends, humans must constantly recall where they left objects or where objects belong. Put simply, humans will make an effort to use spatial decomposition to decrease cognitive load while organizing information in their world.

Whether using a physical desktop in the real world or a virtual desktop on a 2-dimensional computer screen, humans use tools in the external world to help them organize information. Therefore, an appropriate organization paradigm for human operators would most likely involve a compromise between highly organized documents in file folders and a more loose organization of document piles spread out in front of them (Jones & Dumais, 1986).

### 1.2.2 Human Information Processing and Information Organization

If reduction of cognitive load is a natural goal for humans when engaging in the organization of information, then it is necessary to explore how information organization fits into overall human information processing. Figure 1, is a model of human information processing adapted from Wickens and Hollands (2000), described in further detail next.

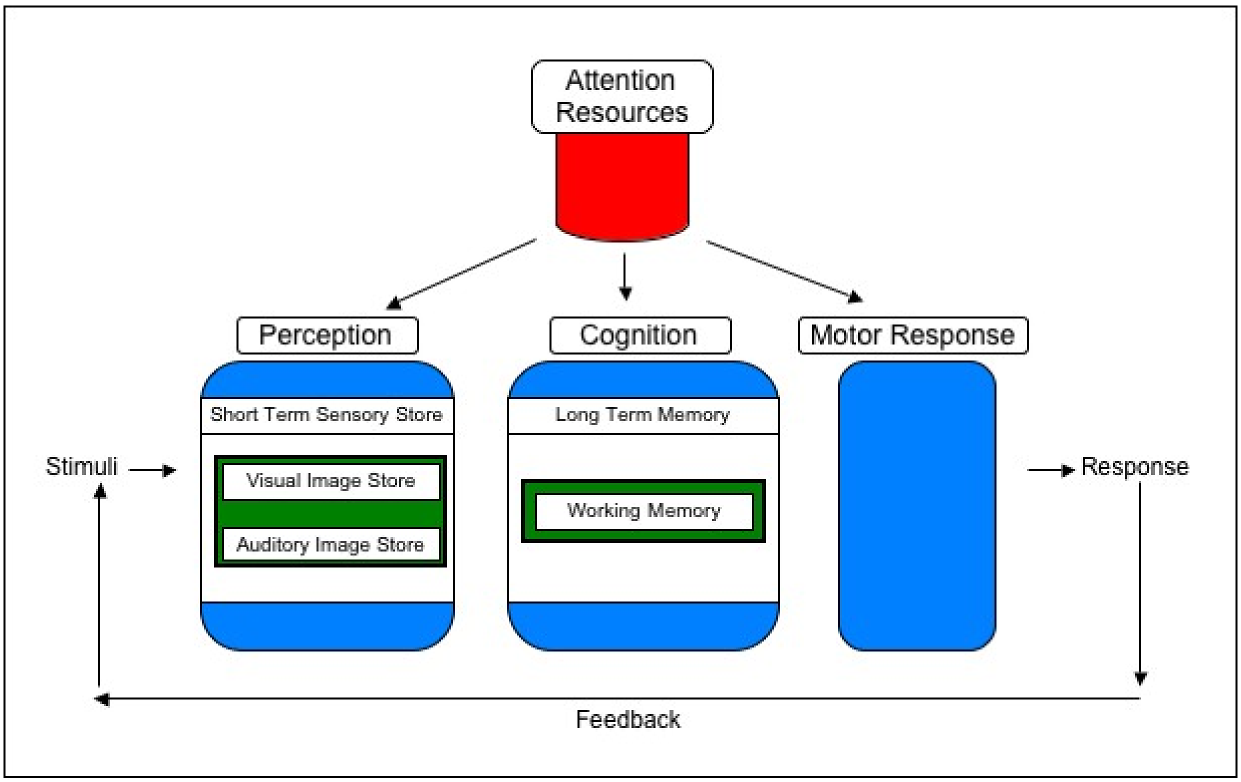


Figure 1 A Model of Human Information Processing (adapted from Wickens & Hollands, 2000).

During the *perception stage*, stimuli are perceived through detection, recognition, identification or categorization. It is important to note that attentional resources are finite and will limit the number of stimuli that can be processed in this manner. The *cognition stage* processes the stimuli through both working and long-term memories. Working memory is characterized, in part, by it's vulnerability to interference and limited capacity, whereas long-term memory serves as the brain's permanent storage system. During the *cognition stage*, attention resources are required to make comparisons between perceived stimuli and information stored in long-term memory. If a physical reaction is chosen during the cognitive stage, it is carried out in the *motor response stage*. This physical response also draws from attention resources.

As information is processed through each stage, it is evident that attentional resources are critical throughout the process. Working memory, in particular, has been a focus of research since it is an attention-demanding store where humans "examine, evaluate, transform and compare different mental representations" (Wickens & Holland, 2000, p. 241). Some of this research has yielded results that may help shed light on why humans organize information the way they do.

Baddeley (1999) broke working memory down into two sub-processes: the visuospatial sketchpad and the phonological loop. These sub-processes are governed by a central executive component that modulates attention to each. The visuospatial sketchpad is particularly important to this discussion since it forms "an interface between visual and spatial information, accessed either through the senses or from LTM [long term memory]" (Baddeley, 2002, p. 88). Wickens and Holland (2000) tell us that mental rotations (i.e., figuring out how landmarks on a map correspond to the world in front of us) involve mental rotations of the information. This information is stored in the visuospatial sketchpad, but also involves the central executive component. Therefore, systems that help reduce the difficulty of mental rotations will further offload cognition.

George Miller (1956) maintains that working memory can handle 7 chunks +/-2, providing full attention is utilized (Wickens & Holland, 2000). If information is properly chunked, it can be processed more effectively, easing the demand on attention resources. This suggests that the format of the material before it is perceived may dictate whether or not the human will have to devote greater cognitive and attentional resources to process it. Hence, a worthy goal would be to design a tool that may allow the user to manipulate and/or visualize data in such a way to promote chunking and recognition.

Returning to the discussion in the previous section regarding methods through which humans organize information, varying the presentation of the information may affect how well humans can remember a given item or group of items by providing a mnemonic structure to the data. Fiore, Johnston and Van Duyne (2004) maintain that mnemonics of this type "(1) help the trainee organize the information conveyed; (2) facilitate the assimilation of new information with related prior knowledge; and, (3) deepen processing and make the information easier to remember" (p. 2564).

### 1.2.3 Visual Context and Information Presentation

Information presentation may also affect how humans perceive and associate incoming stimuli (e.g., visual) with information that already resides in memory. In the case of interface design, visual data can be presented with context to further aid the linking of semantic information with relevant spatial information.

Visual context, or "the global configuration of all items", may aid both the ability to recall information and the ease by which subjects locate embedded target information during visual search (Chun & Jiang, 2003, p. 231). In other words, visual context helps to guide visual attention through the process of contextual cueing (Chun & Jiang, 1998). The guidance of visual attention through contextual cueing is indicative of the meaningful relationships between objects in a visual scene. The configuration of the visual cues, in this instance, form detectable patterns. Since humans excel at recognizing and understanding visual patterns, visual context may provide the perceptual cues necessary to form patterns, which may help humans interpret information more readily (Li, Feng & Li, 2001).

According to Tulving's (1983) encoding specificity principle, the effect of relevant context (e.g., geographical map presentation) may help a human remember other information associated with that location (e.g., the status of emergency responders) simply because contextual information is closely related (or is identical to) the semantic information regarding that location. Therefore, designing displays that provide *relevant* visual context may further assist the human operator in recalling relevant information when performing tasks of a spatial nature (e.g., IOC operators attempting to remember information regarding specific events at specific locations).

### 1.2.4 Information Visualization and Spatial Cognition

At the least, humans will want information organization software to help them do the same things the physical table does: help them organize information while decreasing cognitive load. At the most, humans want the tool to help them perform the task even more efficiently and effectively than conventional methods. Card, Mackinlay and Schneiderman (1999) maintain that externalizations and visualizations of information may actually augment the processing capability of a user by reducing load on their working memory.

For example, principles of information visualization have been applied to geospatial interfaces in the field of Geographical Information System (GIS) development. In GIS systems utilizing standard screen sizes, screen space becomes a critical issue. Therefore, a balance between the display of low-level information display and high-level information (i.e., global) must be achieved. This balance must be found while maintaining a relational link between detailed information and global context (Tory & Moller, 2004). Kosara, Miksch and Hauser (2001) created a function in a GIS system which highlighted the shortest of all possible routes between two cities by actively blurring the longer routes. Such techniques provide perceptual cues to the user which can help them locate relevant information more rapidly. However, this type of visualization paradigm is not always practical since it can potentially obscure important visual cues. Combining techniques in visualization with the capabilities inherent to spatial interfaces may serve to improve spatial cognition and further offload working memory.

### 1.2.5 Situation Awareness and Performance

How information is presented and organized may also influence an operator's *situation awareness*. Situation awareness (SA) can be defined "the perception of elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of status in the near future" (Endsley, 2000, p. 3). Thus, SA consists of three levels: level 1 - perception, level 2 – comprehension, and level 3 - projection. Although SA is not directly linked to performance, the relationship between these two constructs can be viewed in terms of a *probabilistic* link (Endsley, 2000). In other words, if an interface can reduce load on the cognitive processes that support building SA, it is possible task performance will increase as a result. Furthermore, limitations inherent to working memory and the availability of attentional resources can limit the human's ability to maintain high degrees of SA (Endsley, 1995; Wickens & Holland, 2000). Hence, SA-oriented design principles can inform the design process to further decrease load on working memory and facilitate task performance.

### 1.2.6 Theoretical Summary

It is possible that designing an interface that closely parallels the spatial organization techniques used in our everyday lives may decrease cognitive load and demands on operators' limited attentional resources. To this end, using techniques in information visualization and the capabilities of spatial interfaces could possibly help support the process of spatial organization without increasing demands on cognitive processes. Finally, it is possible that these cognitive load reductions may improve SA and overall performance (e.g., recall and decision making) in an information organization task.

## 1.3 Prior Art

A brief review of prior art was conducted to inform the design process.

### 1.3.1 Data Mountain

In 1998, Robertson et al. of Microsoft's Research division developed an interface known as Data Mountain to facilitate document management by leveraging human spatial memory abilities (Figure 2). The software was designed to help a user organize his/her web page bookmarks. The interface used small thumbnail representations (with drop down shadows) of the actual web pages for each bookmark. When the mouse moved over a given thumbnail, a halo would surround the corresponding bookmark and a small pop-up label containing the bookmark's title would appear immediately (zero-hover time). The pop-up labels would be the same size regardless of the bookmark's position on the mountain. If the user clicked on a thumbnail, it would 'explode' to full size, allowing the user to view a high-resolution version of the thumbnail. At that point, the user either selected the hyperlink to navigate to the corresponding web page or clicked on the appropriate control to put the page back into its original state.

Figure 2 Data Mountain (Robertson, et al., 1998).

Spatially, Data Mountain was unique in that the bookmarks could be dragged about on a continuous planar surface (tilted backwards 65 degrees from the user) via a mouse. The 'higher' the thumbnails were positioned on the mountain, the smaller they would appear, thus providing the illusion of perspective (known as 2.5D). To aid in organization, fixed landmark silhouettes were provided in the form of circles were scattered throughout the workspace.

As the user moved the bookmarks around the mountain, other bookmarks would move out of the way in a predictable 'domino style affect.' This algorithm also prevented occlusion and did not allow bookmarks to occupy the same space. Spatialized audio was used to further leverage other sensory modalities. A humming sound would accompany the movement of bookmarks as they were dragged around the workspace. The acoustic pitch would increase as the bookmark moved towards the bottom of the mountain and vice versa.

The creators of Data Mountain concluded that the software was effective at leveraging spatial memory ability because users could view the whole workspace at once, which allowed them to see spatial relationships amid their own informal arrangement of information. Findings showed that this aspect of spatial memory's influence led to reduced storage times, retrieval times, and retrieval failures (Robertson et al., 1998).

#### 1.3.1.1 Data Mountain: Thumbnails vs. Icons

Czerwinksi, van Dantzich, Robertson and Hoffman (1999) conducted a study comparing the original prototype of Data Mountain described above to a version that used blank icons for each bookmark (Figure 3). During the study, the participants were tasked with locating the appropriate bookmark on the data mountain display that corresponded to one of four types of cues: the title of the page (i.e., the bookmarked page), a one or two sentence summary of the page's content, a thumbnail image of the page, and all three cues simultaneously. The participants ran through 25 trials of each cueing condition, half of which had the thumbnails on the bookmarks turned off. In this scenario, the only way the user could definitively distinguish between the bookmarks was by opening them up and looking at them. Notably, after a brief adjustment period, the participants performed just as well with the thumbnails on as with the thumbnails turned off. However, the feedback indicated that the participants preferred the thumbnails version.

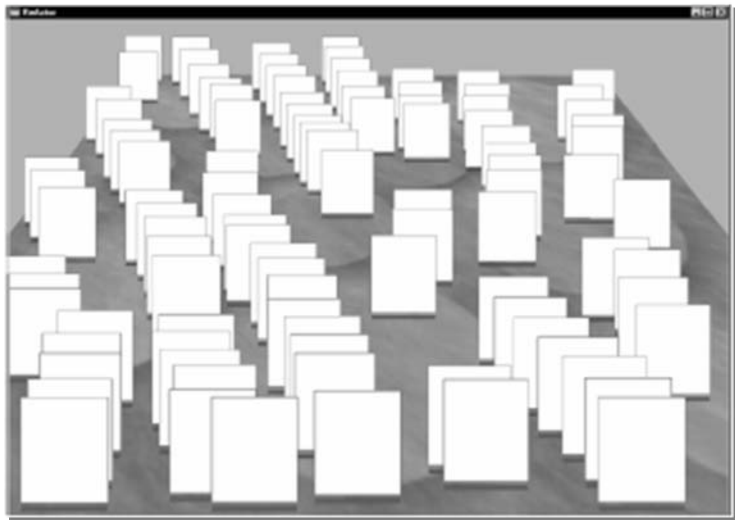

Figure 3 Robertson's Data Mountain Without Thumbnail Pictures.

These results have important implications for the present study because Internet bookmarks naturally afford the use of thumbnails rich in visual detail as opposed to document management systems (e.g., email software) that are largely text oriented. Czerwinksi et al. have shown that the presence of thumbnails, though preferred, are not necessarily related to the performance enhancements offered by the spatial nature of the Data Mountain paradigm. Furthermore , the authors felt their results suggest that adding a title mouse-over function for the bookmarks may enhance performance for situations where thumbnails are not helpful (e.g., when purely non-graphical content is being manipulated). Therefore, it should not be necessary to add a high level of visual detail to the thumbnail graphics that will represent incident reports in the prototype (see 1.4.1).

### 1.3.2 Information Cockpit (InfoCockpit)

Tan, Stefanucci, Proffitt and Pausch (2001) were critical of the Data Mountain prototype in that it did not provide "the user-centered cues that help in remembering locations" (p. 2). Therefore, they designed a system known as the Information Cockpit (InfoCockpit). The interface provided "users with distinctive cues for both location and place to improve their recollection of material presented" (p. 1). In their study, participants were first trained on 3 separate lists of 10 word pairs: one cue word and one target word. Participants learned the words in both the desktop condition and the InfoCockpit condition. The desktop condition utilized a standard desktop computer set up in a conventional manner with one monitor.

For the InfoCockpit condition, three monitors were set up as follows: one immediately in front of the participant, one immediately to the left of the front monitor and one to the right. The goal of this set-up was to provide location cues by surrounding the participant with environmental visuals displayed via projection systems (140 degree horizontal view) behind the three monitors to help associate location with learning. Each of the three lists was displayed separately on each of the three monitors. When each of the three lists was displayed, a different panoramic image displayed on the screen behind the monitors along with sound corresponding to that particular imagery. The panoramic images corresponded the list tiles (e.g., a panoramic picture of a museum was displayed for the word list titled 'museum').

Using this technique, the researchers hoped to provide retrieval cues to provide location cues and subsequently aid the users' recall ability. Indeed, in the InfoCockpit condition, participants recalled 56% more information than those using desktop computers. The author's findings suggest that location and place were effective in helping users remember semantic information as compared to a standard display.

### 1.3.3 SA-Oriented Design Principles

According to the SA-Oriented Design Principles, proposed by Endsley, Bolte, and Jones (2003), information might lose its reliability or timeliness once a particular time threshold has been crossed, resulting in a loss of SA. Thus, it is recommended that visual cues, such as a slowly fading representation of an information object (e.g., an icon), may serve as a salient cue of timeliness. Since information may be constantly updated during a crisis, it is possible multiple emails would arrive in quick succession, each updating the previous information regarding a particular subject. Therefore, it may be advantageous to incorporate a design feature into the spatial interface that highlights the timeliness of the information presented.

## 1.4 Design Proposal

The following design proposal is a product of the preceding exploration of theories and prior art. Effort has been made to integrate both theoretical guidelines and lessons learned by other researchers to arrive at a notional prototype that represents the logical next step in the evolution of spatial information management interfaces.

### 1.4.1 Prototype Concept: Incident Report Visual Organizer

The prototype design concept to be evaluated in this study will be known as the Incident Report Visual Organizer (IRVO). In the proposed experimental setting, the design is intended to elicit participants' spatial and contextual encoding abilities as they organize and integrate incident reports during a rapidly changing crisis situation. The IRVO was designed to provide the necessary perceptual cues to help the participant process the visual context of the information. These perceptual cues are discussed in further detail below.

The IRVO will build on some of the design concepts used successfully in prior studies (Appendix A). Some functionality was inspired by Data Mountain (Robertson et al., 1998). For instance, similar to Data Mountain, the IRVO will have the following functionality:

- Moving the mouse cursor over an incident report thumbnail will reveal the contents of the report virtually instantaneously in a set of information boxes at the bottom of the screen—as opposed to simple descriptive label in Data Mountain.

- Clicking on an incident report icon ‘explodes’ it to full size so that the participant may read the report in its own window, if desired.
- Participants will be able to drag the incident reports from the inbox to any location on the screen they desire, but instead of an algorithm which bumps other incident reports out of the way while they are dragged, the IRVO simply moves incident reports out from underneath each other if they are inadvertently stacked one on top of the other by the participant. In this way, the IRVO prevents occlusion.
- The background of the IRVO will be similar to Data Mountain in that it provides landmarks to aid in organization; however, the IRVO will have a map of the area where the incidents are taking place. Furthermore, unlike Data Mountain, the map will not be canted back at angle, nor will there be any spatialized audio. These features are not considered relevant to this study. The map included in the IRVO interface is intended to provide location-related perceptual cues to help the participant process the visual context associated with the information presented. Since the map is a central component of the information organization task, it is intended that co-locating the map information with the incident report information will help the participant build visual context. Specifically, this design feature provides a means for participants to co-locate spatial information (i.e., location of the incident) with semantic information (i.e., incident report textual content), which is represented by incident report icons. As the participant places the icons on the map, the visual cues provided by the geographical features on the map become each icon’s visual context. In other words, the features of the map may

help the participant create recognizable patterns which can aid in information retrieval.

Based upon the study conducted by Czerwinski, et al. (1999), the incident report icons are a simple purple color, rather than actual thumbnails of the incident reports themselves. Though contradictory to the original Data Mountain thumbnails, the textual content of the incident reports are not conducive to thumbnail imagery. The background map provides some contextual clues to aid in recall, similar to the context provided in the InfoCockpit (Tan et al., 2001). Finally, in keeping with SA-Oriented Design Principles, to provide the participant with perceptual cues regarding the timeliness of the information, the incident report icons change color to blue (from the original purple) when they are more than 5 minutes old. The 5-minute time interval was chosen arbitrarily based on duration of each scenario (i.e., 20 minutes).

### 1.4.2 Hypotheses

The following hypotheses were proposed for investigation in this study:

Users utilize the hierarchical folder paradigm in conventional email software systems to organize their emails. This effort is intended to reduce the amount of time it takes to retrieve information later. But this type of file organization paradigm can make context building and email organization more difficult at the onset of an emergency scenario. Therefore, I predicted:

H1: *When compared to conventional email software with hierarchical file organization paradigms, a spatial interface may decrease the time necessary to organize information into meaningful clusters.*

It is possible that conventional software systems utilizing standard hierarchical folder organization paradigms increase cognitive load, thus diminishing SA. Therefore, I predicted:

H2*: It is possible that a spatial interface will allow the user to build relationships and context between documents faster and with less cognitive load, allowing them to further improve their level 1 SA.*

It is possible that the information retrieval from human memory while performing tasks that involve information with spatial characteristics (i.e., tasks requiring the association of information with events at specific geographical locations) is more difficult when spatial context is not co-located with pertinent information. Therefore, I predicted:

H3: *A display design that provide relevant visual context co-located with relevant spatial information may further assist the human operator in recalling pertinent information when performing tasks of a spatial nature.*

# 2.0 METHODOLOGY

## 2.1 Participants

Twenty participants (age range = 18-40), half male and half female, were recruited voluntarily from the student body of the University of Central Florida (UCF). Participation in the experiment was open to all students, regardless of age, race, gender, or nation of origin. They received a small monetary incentive for their participation. Treatment of these participants was in accordance with the ethical standards of the APA. No prior experience in crisis management was necessary.

## 2.2 Experimental Design

This study used a one factor within-group design, with the interface (MS Outlook vs. IRVO) as the within-group independent variable. Presentation of the interfaces was counterbalanced such that half of the participants started on the prototype IRVO interface and half on MS Outlook. Dependent measures included assessment of situation awareness, task performance, and cognitive load.

## 2.3 Interfaces

One of the main features of this study was to evaluate how the difference between the interfaces in the control condition (MS Outlook) and the experimental condition (IRVO) would affect performance.

### 2.3.1 MS Outlook Interface

Participants in the control condition had three tools at their disposal to conduct the task: MS Outlook, a notepad and a paper map of the metropolitan area where the crises took place. It is important to note that the map was of a portion of a city most likely unfamiliar to most participants. These maps were obtained via Google Earth. Great care was taken to avoid major cities in effort to prevent recognition of prominent landmarks. The participants received incident reports in the form of e-mails at random intervals. The e-mails arrived in an e-mail *inbox* folder. The inbox folder had an indicator next to it showing the number of unread e-mails that have accumulated. Participants were permitted to organize this incoming information in any manner desired (e.g., creating folders and/or opening multiple e-mails simultaneously). They had a pen available to them so that they could make notes on the map or on the notepad adjacent to their computer.

### 2.3.2 IRVO Interface

Participants in the experimental condition used the mouse-driven IRVO interface on a conventional personal computer. All participants had access to a map just as they did in the control condition; in this case, however, it served as the backdrop of IRVO display interface. The map also differed from the one used in the control condition in that it was of a completely different location. The incident reports for this interface were also in an e-mail format (i.e., header information including the e-mail's author, date/time the e-mail was written, and a subject line followed by content). The reports arrived in an *inbox* at the bottom right-hand corner of the screen. This control literally looked like a box (Appendix A). The box had a number just below it indicating how many unread incident reports it contained. To view a message, the participant simply had to move the mouse over the message to read it in the information panel at the bottom of the screen. The participant could also left-click on the message and drag it out of the inbox and over the rest of the screen as they desired. Once the message was removed from the box, the participant could also click on a small yellow box on the upper right hand corner of each message to explode the message to full size so they could read it instead of using the mouse-over function. Four buttons, one at each corner of the full size message, could be left-clicked once to return the message to its original size. An algorithm prevented the thumbnails from obscuring one another when the participant was not manipulating them. This algorithm also prevented a participant from accidentally leaving one message directly on top of another message when outside of the inbox. The participants had the option to use one of three types of icons to help them organize information more efficiently: a car accident icon, a fire icon and a toxic spill icon (Figure 3). These 'incident' icons were located in the bottom left hand corner and could be dragged around the map to mark areas of interest. The 'incident' icons were programmed to stay below message icons at all times to prevent occlusion.

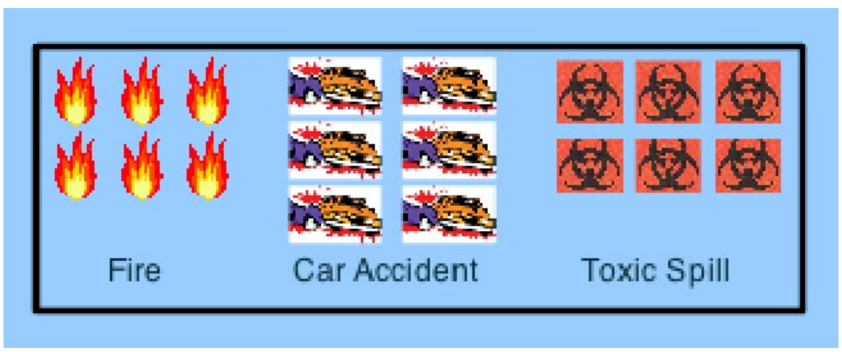


Figure 4 IRVO Incident Icons

Two small buttons on the bottom of the screen (Figure 4) provided the participants with the ability to resize the message thumbnail icons to a more comfortable level: one with a plus sign (to make all the message thumbnail icons larger) and one with a negative sign (to make all the message thumbnail icons smaller); this allowed the user to see an unobstructed view of the city and relevant landmarks so that they may orient themselves as desired.

Lastly, the participants had the option of dimming all message and incident icons on the screen simply by moving their mouse over a button marked 'Dim' (Figure 4) on the lower part of the screen. This function was intended to allow the participants to view the names of all the streets on the map should they be occluded by icons.


Figure 5 IRVO Icon Adjustment Panel

## 2.4 Scenarios

Two versions of an emergency information management scenario were created for each condition. Participants experienced both versions of the scenario, one using the MS Outlook interface and one using the IRVO display interface. The city and individual incidents were different in each scenario. However, both scenarios lasted exactly 20 minutes and both scenarios contained exactly 48 randomly delivered incident reports. Participants collected, viewed, and organized incident report information as it arrived. It is important to note that the incident reports arrived at random, but each either reported something new or updated information about a prior incident. It is here that organization of information and context building became key. The following is an example of how a scenario unfolded:

In both scenarios, independent of the interface, incident reports (Table 1) arrived regarding events in the area. For instance, one report may have come from emergency services stating that a fire had been reported at a specific intersection in the downtown area. Next, a report would come in stating that an oil tanker had over-turned on a specific highway. Next, a report came in stating that two fire trucks had been dispatched to the fire at the intersection reported earlier. After that, another report would come in stating that three ambulances had been dispatched to the highway pile-up. Reports continued in this fashion for the duration of the scenario. During the initial briefing, the participant was informed that RFI events were their top priority and they should make every effort to maintain awareness of the status of all events that had occurred (see 2.6).

Table 1 Sample Incident Report Content

| | |
|---|---|
| **From:** | Dispatch11@ERC.GOV |
| **Date:** | March 21, 2007, 12:02:55 |
| **Subject:** | E. Main St. and S. Broadway St. Fire |
| **Message:** | Police Precinct 12 has dispatched 4 units to the fire. |

## 2.5 Task Performance

As indicated earlier, three RFI events occurred during each scenario regarding some specific aspect of one or more incidents. These events occurred at the 3-minute, 9-minute and 15-minute time intervals during the 20-minute scenario in each condition. For each RFI event, participants were presented with a maximum of two questions and were told that they had exactly 90–seconds to respond to both questions (Table 2). Further, participants were instructed that responding to these questions was their top priority. Participants answered the questions by typing an answer utilizing the keyboard in front of them. If the participant did not answer the first question, they would not see the second question. The participants also had the option of typing ‘I do not know’ as an answer, in which case they would advance to the next question, if any. A countdown clock was clearly visible just below the question so that the participant could determine how much time they had left during the RFI event. It is important to note that the scenario was *not* paused during the RFI event and the participants were told that the answers to the RFI questions would not be found in the messages that were coming in during the event. For instance, at some point during the scenario, an RFI popped up on the screen to the left of the participant with the following question: *"Which police precincts (as in precinct number) have been notified about fire incidents so far?"* This information was contained somewhere in the reports the participant had already received. No feedback was provided to participants regarding the accuracy of their responses nor were they given information on how there responses were going to be scored.

Table 2 RFI Question Descriptions

| **Outlook Condition RFI Questions** | | | |
|---|---|---|---|
| **Event #** | **Type** | **Question #** | **Question Description** |
| 1 | Semantic | 1 | Which police precincts (as in precinct number) have been notified about fire incidents so far? |
| 1 | Spatial | 2 | How many fires have been reported South of Deke Slayton Highway/Blvd? |
| 2 | Spatial | 3 | How many incidents have occurred between Sampson Pkwy and Deke Slayton Highway/Blvd (exclude events Eat of Highway TX-248)? |
| 2 | Semantic | 4 | Which Ladder has been notified about the fire at Highway 2094 and Lighthouse blvd? |
| 3 | Semantic | 5 | Which Incident required notification of St. Andrews Hospital? |
| 3 | Spatial | 6 | How many incidents have occurred between Sampson Pkwy and Deke Slayton Highway/Blvd (exclude events East of Highway TX-248)? |
| **IRVO Condition RFI Questions** | | | |
| **Event #** | **Type** | **Question #** | **Question Description** |
| 1 | Semantic | 1 | What type of vehicle caused the incident located at Highway 146 South of the Fairmont Intersection? |
| 1 | Spatial | 2 | How many Police units have responded to events West of Highway 146 (TX-146)? |
| 2 | Spatial | 3 | How many Police units have responded to events West of Highway 146 (TX-146)? |
| 2 | Semantic | 4 | How many units has Ladder 8 sent to the incident at the airport? |
| 3 | Semantic | 5 | Which incident has caused units to request backup? |
| 3 | Spatial | 6 | How many Fire units have responded to events East of Highway 146 (TX-146)? |

RFI questions were divided into two types: *semantic* and *spatial*. To respond to a semantic question, participants would need to access primarily text-based information, such as found in the content of the e-mail message. An example of a *semantic* question would be "How many fires have occurred so far?" To respond to a spatial question, participants would need to access information related to, for example, a location on the map. An example of a *spatial* question would be "How many fires have occurred WEST of highway 146 so far?" For each of the three RFI events, one question of each type was administered to the participant. In this way, a total of six RFI questions were administered to each participant, provided they did not run out of time answering the first question in each RFI event.

Additionally, the system recorded the time (in seconds) for each participant to answer each RFI question. Task performance was assessed in terms of time on task to retrieve the requested information and the accuracy of responses. It should be noted that one question was repeated in each condition to see if participants could follow along and update the information regarding those specific questions.

## 2.6 Situation Awareness

A simple SA survey consisting of four queries (Table 3) was used to assess participants' level 1 SA during the scenarios. The SA survey was administered at the end of each scenario. These questions were focused on Level 1 SA (i.e., perception-focused questions) only since it was deemed inappropriate to ask Level 2 and/or Level 3 due to the simplicity of the tasks in each condition.

As with the RFI questions, there were two *semantic* level 1 SA queries and two *spatial* level 1 SA queries in each survey. These queries were alternated in presentation (i.e., one spatial query, followed by one semantic query, etc). Participants' responses to the SA survey queries were compared to ground truth, providing an objective measure of the degree to which their perceptions and assessments of the current situation are accurate representations.

The queries were presented using a multiple-choice format. The SA survey queries were similar to those in the RFI questions, but differed in one key aspect: the participants were *not* allowed to refer to any of their incident reports or notes while answering the queries. In addition, the participants were given just 60 seconds to answer all four queries. Performance on the SA survey queries was scored in terms of number correct.

Table 3 SA Question Descriptions

| **Outlook Condition SA Questions** | | |
|---|---|---|
| **Question #** | **Type** | **Question Description** |
| 1 | Semantic | What type of incidents occurred on the East side of Highway TX-248? |
| 2 | Spatial | How many incidents reported casualties? (answer not available) |
| 3 | Spatial | Did more incidents occur North, South, East or West of Deke Slayton Highway? |
| 4 | Semantic | How many fires occurred? |
| **IRVO Condition SA Questions** | | |
| **Question #** | **Type** | **Question Description** |
| 1 | Spatial | How many car accidents occurred? |
| 2 | Semantic | Which type of accidents occurred more frequently West of TX-146? |
| 3 | Spatial | How many fires were brought under control? |
| 4 | Semantic | How many incidents occurred North of Spencer Highway? |

## 2.7 Cognitive Load

Participants' cognitive load during completion of the tasks was assessed using subjective measures including the NASA-TLX and the Participant Subjective Situation Awareness Questionnaire (PSAQ). The NASA-TLX (Hart & Staveland, 1988) consists of a 6-item questionnaire that asks participants to rate their levels of perceived workload on a 20-point scale in terms of mental demand, physical demand, temporal demand, performance, effort, and frustration (see Appendix B). Perceived workload can be assessed by examining participants' total score, summed across all of the components. The PSAQ (Matthews, Pleban, Endsley & Strater, 2000) consists of three items (see Appendix C) designed to solicit self-perceived report of participants':

- Workload during the scenario
- Performance during the scenario
- Situation awareness / awareness of the evolving situation

These items are rated on a 5-point rating scale, with responses ranging from 1 (low value) to 5 (high value). The NASA-TLX and PSAQ measures will be administered following completion of each scenario.

## 2.8 Apparatus

Both interfaces were deployed on a Sony VAIO Laptop Personal Computer (PC) with a 1.5 GHz Intel Processor and 256 Megabytes of memory. MS Windows XP professional was the resident operating system on the computer. The laptop was wired to a 19-inch external desktop LCD display and received control inputs via a USB mouse and keyboard. The MS Outlook and IRVO software applications were deployed on the laptop system, but the display interfaces were relocated to the larger external monitor. The software measures were displayed on the laptop's primary monitor to the left of the participant as appropriate. The control task interface software was conventional MS Outlook (2003 version). The IRVO software was written in Actionscript 2.0 and Flash programming code and displayed via the integrated Flash Plug-in on Internet Explorer version 6.1.

The MS Outlook interface received the e-mails (i.e., incident reports) via CMail mail server software that, in turn, received e-mails from a pre-programmed software agent system written in Visual Basic. The CMail server software was accessible to the laptop via an isolated local area network (LAN). All other computerized measures (SA questions, RFIs, NASA-TLX) were written in Visual Basic. The computerized measures were activated remotely by the evaluator from a Dell Laptop via the LAN. The PSAQ was administered via paper and pen.

## 2.9 Procedure

Upon arrival, participants were asked to complete an informed consent form and a demographic survey (see Appendices D and E, respectively). Participants were then briefed as to the purposes of the experiment as well as provided with an explanation of the task they were asked to perform (see Appendix F). Participants were then randomly assigned to one of the two experimental conditions (MS Outlook first – IRVO second vs. IRVO first – MS Outlook second). The RFIs were presented at their pre-planned intervals during each scenario. Additionally, the SA survey was presented at the end of each scenario. After finishing each condition, participants were asked to complete the NASA TLX and PSAQ measures (Appendices B and C, respectively). Participants were then debriefed and any questions they may have had regarding the experiment were addressed. Altogether, the experiment, including paperwork and task performance, took approximately 90 minutes.

## 2.10 Scoring

The RFI questions were scored using the following assumptions:

- Out of six possible questions, only the questions answered correctly were awarded a score of one point
- If a question required two answers, the participant was awarded a half point if they provided only one correct answer
- Incorrect answers were awarded zero points

- If an RFI question was not answered due to the participant running out of time, the question was awarded zero points.

The SA survey questions were scored using the following assumptions:

- Out of four possible queries, only the questions answered correctly were awarded a score of one point
- No partial credit was awarded since the answers for SA survey queries were multiple choice

If an SA query was not answered due to the participant running out of time, the question was dropped from the analysis.

# 3.0 RESULTS

## 3.1 Data Analysis

Data was analyzed using repeated measures *t*-tests and one-way ANOVAs, with the interface serving as the independent variable. Separate analyses were conducted for each of the dependent measures. An alpha level of .05 was used for all statistical analyses.

## 3.2 RFI Performance

### 3.2.1 RFI Accuracy

The RFI questions were analyzed via one-way ANOVA. When compared to one another between conditions (*n*=20), individual RFI score averages revealed no significant results (Table 4). Nor did RFI scores differ significantly when segregated into *spatial* and *semantic* subtotals (Table 5) or overall averages (Table 6) between conditions.

Table 4 One-way ANOVA: Individual Overall RFI Question Scores

| Dependent Variable | Outlook | IRVO | *F* | *p* |
|---|---|---|---|---|
| RFI Question 1 | .900(.308) | .850(.366) | $F(1,38)=.218$ | .643 |
| RFI Question 2 | .778(.429) | .600(.503) | $F(1,36)=1.363$ | .251 |
| RFI Question 4 | .813(.403) | .895(.315) | $F(1,33)=.459$ | .503 |
| RFI Question 5 | .583(.354) | .400(.308) | $F(1,36)=2.921$ | .093 |
| RFI Question 6 | .462(.519) | .273(.467) | $F(1,22)=0.863$ | .363 |

Table 5 One-way ANOVA: RFI Overall Semantic and Spatial Subtotals

| RFI Question Subtotals | Outlook | IRVO | *F* | *p* |
|---|---|---|---|---|
| Total RFI Semantic Scores | 2.08(.693) | 2.10(.852) | $F(1,38)=.010$ | .919 |
| Total RFI Spatial Scores | 1.05(.524) | .750(.550) | $F(1,37)=3.09$ | .087 |
| Overall Score | 3.08(.921) | 2.85(.780) | $F(1,38)=.695$ | .410 |

Table 6 One-Way ANOVA: Overall Average RFI Question Scores

| Average RFI Question Subtotals | Outlook | IRVO | *F* | *p* |
|---|---|---|---|---|
| Average Semantic Scores | .771(.232) | .708(.275) | *F*(1,38)=.603 | .442 |
| Average Spatial Scores | .684(.342) | .525(.413) | *F*(1,37)=1.71 | .199 |
| Overall Average Score | 1.59(.454) | 1.43(.390) | *F*(1,38)=1.48 | .232 |

### 3.2.2 RFI Response Times Regardless of Accuracy

RFI Response times regardless of accuracy were analyzed via one-way ANOVA. Mean overall average raw response times (seconds) for RFI questions 1, 2 and 5 (Table 7) were not significant. However, raw response times for RFI question 4 were significantly higher for the Outlook condition as opposed to the IRVO condition. Furthermore, the overall raw response time for RFI question 6 was lower in the Outlook condition as opposed to the IRVO condition.

Raw RFI response times for each participant were subdivided into *semantic* and *spatial* overall raw response times and subtotaled for each participant (Table 8). The results were not significant. However, an analysis (Table 9) of overall average *spatial* raw response times between conditions revealed that participants averaged significantly higher overall raw *spatial* response times (*M*=27.6 seconds) in the IRVO condition, than in the Outlook condition (*M* = 18.9 seconds).

Table 7 One-way ANOVA: RFI Raw Response Time Regardless of Accuracy

| Dependent Variable | Outlook | IRVO | *F* | *p* |
|---|---|---|---|---|
| RFI Question 1 | 32.0(14.1) | 28.3(8.18) | *F*(1,38)=1.03 | .317 |
| RFI Question 2 | 18.5(10.4) | 24.8(11.4) | *F*(1,37)=3.19 | .082 |
| RFI Question 4 | 17.0(5.83) | 12.5(3.82) | *F*(1,33)=7.60 | .009 |
| RFI Question 5 | 51.7(21.1) | 44.4(19.7) | *F*(1,36)=1.24 | .273 |
| RFI Question 6 | 20.0(8.83) | 30.8(16.3) | *F*(1,23)=4.53 | .044 |

Table 8 One-way ANOVA: Raw Response Time Overall Subtotals Regardless of Accuracy

| RFI Question Subtotals | Outlook | IRVO | *F* | *p* |
|---|---|---|---|---|
| RFI Raw Semantic Times | 92.2(28.7) | 84.5(23.1) | *F*(1,38)=.861 | .359 |
| RFI Raw Spatial Times | 31.6(16.6) | 41.7(20.2) | *F*(1,38)=3.01 | .091 |
| Overall Score | 123.7(33.4) | 126.2(26.3) | *F*(1,38)=.069 | .794 |

Table 9 One-way ANOVA: Raw Average Response Time Regardless of Accuracy

| Average Raw RFI Response Times | Outlook | IRVO | *F* | *p* |
|---|---|---|---|---|
| Average Semantic Response Times | 34.7(11.7) | 28.8(8.13) | *F*(1,38)=3.38 | .074 |
| Average Spatial Response Times | 18.9(7.77) | 27.6(10.7) | *F*(1,38)=8.61 | .006 |
| Overall Average Score | 29.1(8.95) | 28.5(7.17) | *F*(1,38)=.051 | .823 |

### 3.2.3 RFI Response Times Based on Accurate Responses

In effort to determine whether or not RFI question response times were significantly different for accurate RFI answers, only response times corresponding with accurate answers to each of the RFI questions were used in this next analysis. Accurate response times for each individual RFI question were compared between conditions for each participant (Table 10). As with the raw response times, mean accurate response times (seconds) for questions 1, 2, 5 and 6 were not significantly different. However, as with the raw response times, the accurate response time for RFI question 4 was significantly higher in the Outlook condition ($M$ = 17.62 seconds) than in the IRVO condition ($M$ = 12.65 seconds). Furthermore, the accurate response time averages for RFI question 6 was marginally significant in favor Outlook.

Just as with the raw response times, the overall average accurate RFI response times were subdivided into *semantic* and *spatial* times and subtotaled (Table 11) for each participant between conditions. A one-way ANOVA revealed significant results. However, when *spatial* and *semantic* times were averages, a one-way ANOVA (Table 12) comparing overall *semantic* accurate response times between conditions revealed that participants averaged significantly higher accurate *semantic* response times in the Outlook condition, than in the IRVO condition.

Furthermore, as with the overall *spatial* average raw response times, a one-way ANOVA found marginally higher overall *spatial* accurate response time averages for the IRVO condition, than the Outlook condition.

Table 10 One-way ANOVA: Individual RFI Accurate Response Time Averages

| Dependent Variable | Outlook | IRVO | *F* | *p* |
|---|---|---|---|---|
| RFI Question 1 | 31.2(14.4) | 28.3(8.64) | $F(1,33)=.524$ | .474 |
| RFI Question 2 | 17.3(11.0) | 20.9(5.84) | $F(1,25)=1.04$ | .318 |
| RFI Question 4 | 17.6(5.94) | 12.6(3.41) | $F(1,28)=8.36$ | .007 |
| RFI Question 5 | 50.4(20.8) | 39.6(16.8) | $F(1,27)=2.32$ | .140 |
| RFI Question 6 | 16.0(2.61) | 33.0(21.0) | $F(1,7)=4.44$ | .073 |

Table 11 One-way ANOVA: RFI Accurate Response Time Average Subtotals

| RFI Question Subtotals | Outlook | IRVO | *F* | *p* |
|---|---|---|---|---|
| RFI Semantic Times | 77.4(31.0) | 65.8(26.7) | $F(1,37)=1.54$ | .223 |
| RFI Spatial Times | 20.9(13.2) | 25.0(9.96) | $F(1,29)=.903$ | .350 |
| Overall Score | 95.2(36.1) | 80.1(31.0) | $F(1,38)=2.02$ | .164 |

Table 12 One-way ANOVA: Overall Average Accurate RFI Response Times

| Average RFI Response Times | Outlook | IRVO | *F* | *p* |
|---|---|---|---|---|
| Average Semantic Response Times | 34.2(11.9) | 26.2(8.38) | $F(1,37)=5.76$ | .022 |
| Average Spatial Response Times | 17.0(8.88) | 24.1(10.6) | $F(1,29)=4.19$ | .050 |
| Overall Average Score | 29.1(9.70) | 25.4(6.00) | $F(1,38)=2.17$ | .149 |

## 3.3 SA Performance

The SA survey queries were analyzed via one-way ANOVA. Two participants were dropped due to data corruption, reducing the sample size to 18 for this analysis.

As with the RFI questions, level 1 SA queries were either *spatial* (queries 1 and 3) or *semantic* (queries 2 and 4) in nature. Each individual SA query score was compared for each participant between conditions. Mean scores for each SA queries 2, 3 and 4 (Table 13) were not significant. However, the SA scores for *spatial* SA query number 1 were found to be significantly higher in the Outlook condition as compared to the IRVO condition. *Semantic* and *spatial* SA score subtotals (Table 14) and averages (Table 15) between conditions were not found to be significant.

Table 13 One-way ANOVA: Individual SA Queries

| Dependent Variables | Outlook | IRVO | *F* | *p* |
|---|---|---|---|---|
| Query 1 (*spatial)* | .722(.461) | .485(.114) | *F*(1,34)=6.08 | .019 |
| Query 2 *(semantic)* | 0(0) | .059(.242) | *F*(1,33)=1.06 | .311 |
| Query 3 (*spatial)* | .438(.512) | .625(.500) | *F*(1,30)=1.10 | .303 |
| Query 4 *(semantic)* | .333(.488) | .333(.488) | *F*(1,28)=0 | 1.00 |

Table 14 One-way ANOVA: SA Query Subtotals

| SA Query Subtotals | Outlook | IRVO | *F* | *p* |
|---|---|---|---|---|
| *Spatial* Subtotals | 1.11(.676) | .889(.676) | *F*(1,34)=.971 | .331 |
| *Semantic* Subtotals | .278(.461) | .353(.493) | *F*(1,33)=.218 | .644 |
| Overall Totals | 1.39(.777) | 1.22(.808) | *F*(1,34)=.397 | .533 |

Table 15 One-way ANOVA: Average SA Query Subtotals

| SA Query Subtotal Averages: | Outlook | IRVO | *F* | *p* |
|---|---|---|---|---|
| *Spatial* Query Average | .583(.354) | .500(.383) | *F*(1,34)=.459 | .502 |
| *Semantic* Query Average | .139(.230) | .177(.246) | *F*(1,33)=.218 | .644 |
| Overall Average | .694(.389) | .639(.413) | *F*(1,34)=.173 | .680 |

## 3.4 Subjective Workload

NASA TLX scores were analyzed via paired sample *t*-test (Table 16). One participant was dropped due to data corruption, reducing the sample size to 19 for this analysis. Though overall NASA TLX scores between conditions were not significantly different, the mental demand subscale did change significantly between conditions. Results revealed that participants found the Outlook condition more mentally demanding than the IRVO condition.

Table 16 Paired Sample *t*-test (two-tailed): NASA TLX Scores

| NASA TLX Subscale | Outlook | IRVO | *t(18) (two-tailed)* | *p* |
|---|---|---|---|---|
| Mental Demand | 23.4(8.13) | 19.1(8.04) | 2.59 | .018 |
| Physical Demand | 0.07(.238) | .105(.315) | -.622 | .542 |
| Temporal Demand | 17.0(8.95) | 17.7(7.42) | -.260 | .798 |
| Performance | 11.1(7.63) | 8.33(6.55) | 1.24 | .230 |
| Effort | 10.7(4.59) | 10.8(6.31) | -.032 | .975 |
| Frustration | 9.46(8.76) | 10.4(9.32) | -.335 | .742 |
| Overall Score | 71.7(16.3) | 66.4(13.1) | 1.13 | .275 |

## 3.5 Subjective SA

Each of the three PSAQ questions was analyzed via one-way ANOVA (Table 17) between conditions. PSAQ ratings were not found to be statistically significant for the perceived cognitive workload question (i.e., "*how hard you were working during this scenario*"). Nor were ratings found to be statistically significant for the perceived performance question (i.e., "*how well you performed during this scenario*"). Lastly, ratings for perceived level of SA (i.e., "*how aware of the evolving situation you were during the scenario*") also did not prove to be statistically significant.

Table 17 One-Way ANOVA: PSAQ Analyses

| NASA TLX Subscale: | Outlook | IRVO | *F* | *p* |
|---|---|---|---|---|
| Mental Demand | 3.58(.847) | 3.55(.759) | *F*(1,38)=.010 | .922 |
| Performance | 2.45(.944) | 2.75(.851) | *F*(1,38)=1.11 | .298 |
| Situation Awareness | 3.00(.649) | 3.00(.129) | *F*(1,38)=0.00 | 1.00 |

# 4.0 DISCUSSION

Overall, the primary metrics for performance in this study were RFI question response time and accuracy. First, the RFI response accuracy data shows no significant performance difference between conditions. H1 was not conclusively proven or disproved. It is possible that longer scenarios with more RFI stops (i.e., larger *k* value) could have produced a more statistically significant effect. However, it is also possible that both software applications facilitated similar performance levels from each participant. Therefore, the effectiveness of the spatial interface cannot be categorically dismissed as ineffective based on the RFI question results. These results are not entirely surprising, since user profiles indicated that 15 out of 20 participants were familiar with MS Outlook and may have incurred a performance benefit in the Outlook condition. This is particularly interesting given that most participants have quite a bit of experience with conventional WIMP interfaces. The novelty of the IRVO interface may have influenced the performance scores just enough to put the prototype on par with MS Outlook—resulting in inconclusive experimental data. Furthermore, participants may have benefited from a short practice session in each condition rather than the instructional pre-test briefing during which they observed the experimenter perform relevant tasks. Further study involving more practice time beforehand may have resulted in more significant performance differentials between conditions.

Results from the RFI response time data analysis are more promising. Analyses of the RFI response times indicate that, on average, the spatial IRVO interface was at least partially effective in reducing the average amount of time necessary to retrieve the information required to answer RFI questions accurately. Interestingly, the spatial IRVO interface was effective in this manner for *semantic* RFI questions as opposed to *spatial* RFI questions where, on average, the Outlook interface proved more effective. These outcomes were mirrored in the raw RFI response time results, which did not differentiate between correct and incorrect answers. It seems, therefore, that H2 was partially proven—but only for certain types of questions. One possible explanation for the IRVO's better performance with *semantic* RFI questions is that the interface did not permit the participants to 'bury' the e-mails in folders, which may have increased the time necessary to locate desired information in Outlook. Furthermore, the IRVO did not require the participants to click on an e-mail message to view the contents. Rather, the IRVO interface allowed the participant to simply cluster related e-mail icons together, leaving each one of them clearly visible at all times. Furthermore, the IRVO interface permitted the participant to simply move their mouse over an e-mail icon to instantly read the contents in a window located at the bottom of the screen (see Appendix A).

One explanation for why the IRVO interface was significantly less effective than Outlook for helping participants answer *spatial* RFI questions more quickly is that the map displayed on the screen in the IRVO interface did not allow the participants to make notes directly on the virtual map. In the Outlook condition, the participants were able to use their pens to make marks on the paper maps. Exactly 18 out of 20 participants were observed marking notes on the map in the Outlook condition. It is possible participants adopted an organizational strategy that made the paper map in the Outlook condition more effective for answering *spatial* questions than the virtual map in the IRVO condition. Furthermore, post-test interviews with some participants revealed that they liked being able to move and rotate the paper map to better orient themselves. It is possible that since the IRVO map was fixed it prevented participants from orienting themselves in an optimal manner.

Though it is possible a spatial interface simply may not help participants locate information faster, it is also possible that the RFI metric was not administered often enough throughout the scenarios to obtain significance. Unfortunately, due to the nature of the timed RFI events, the second question in each event was not answered often enough to provide adequate statistical power. Perhaps longer scenarios and more RFI events would provide the necessary power to determine definitively whether or not spatial interfaces help participants answer questions faster and more accurately.

SA performance results were inconclusive. Results from SA query 1 indicate participants were able to answer a *spatially* oriented query more accurately in the Outlook condition than in the IRVO condition. This evidence serves to support results from the RFI response time analysis, in that factors in the Outlook condition seemed to help participants' answer *spatially* oriented questions more accurately. It seems that H3 was not conclusively proven or disproved. However, since the SA queries were administered in a manner that forced participants to recall information from long term memory, high levels of accuracy on *spatially* oriented queries could be considered quite significant. Thus, it is possible that factors in the Outlook condition were significantly more conducive to assisting participants in not only locating information in a spatial manner, but recalling it as well.

In any event, the following factors should be considered when interpreting these results: the relatively low number of SA queries (i.e., 2 *spatial* and 2 *semantic*), the lack of variance in scoring (i.e., 0 points for a wrong answer and 1 point for a correct answer), the 60 second time limit, which sometimes prevented participants from answering all the queries; and the queries were designed to assess level 1 SA only. These factors may be responsible for the lack of significance in SA query results and may also suggest that even highly significant scores would be questionable due to the lack of variance offered by such a small number of queries.

Participants' subjective evaluations of their workload, performance and SA were generally not significant. However, one key element of the NASA TLX, the mental demand subscale, indicated that participants felt the Outlook condition was more mentally demanding than the IRVO. The fact that the Outlook interface was considered significantly more mentally demanding, especially with the participants having no experience with the IRVO, can be considered a very positive subjective result for software configured in a spatial fashion. It is possible that the participants felt that the IRVO was less mentally demanding simply because the interface was less sophisticated in it's functionality as compared to Outlook. In other words, participants may have felt that Outlook was more mentally demanding because they had to spend more time digging through folders to find e-mails rather than simply moving the mouse over the e-mails to read content as they would with the IRVO interface.

## 4.1 Limitations and Considerations for Future Research

Several limitations to the present study should be noted. First, the participants used in this study were inexperienced college students, which raises concerns about participants' motivation to perform well in the scenarios. Consequently, external validity of this study is low and this limits the generalizability of these findings to more realistic complex task environments. Future research needs to explore the utility of spatial interfaces with a more experienced, operationally-valid population.

Second, although the interfaces were counterbalanced, qualitative albeit minor differences between the two scenarios may have influenced the results over and above the differences between the two interfaces. Future research should, therefore, counterbalance the scenarios in addition to the interfaces to ensure that significant differences are due solely to the design of the interfaces.

Finally, an important consideration in the design of spatial interfaces is effectively dealing with the potential clutter that may result during extended scenarios as information continues to be received (cf. Feiner, MacIntyre & Seligmann, 1993). Future research, therefore, must determine how best to minimize clutter on the display, such as creating a means of archiving ‘old’ messages while still providing ready access to this information, as needed.

# 5.0 CONCLUSION

Though neither interface proved to enhance human performance significantly better than the other, it is possible that a spatial interface (i.e., the IRVO) may show some promise in helping users build context faster and retrieve information more efficiently. However, the IRVO did not help participants perform significantly better, on average, with *spatially* oriented questions as opposed to *semantically* oriented questions. Given the presence of MS Outlook in the business and academic environments, it is quite compelling that a novel interface was able to do at least as well as its predecessor for assisting users in answering semantic RFI questions.

Though no correlation between timing and accuracy was found, it possible that the small number of viable RFI questions used for comparison was a contributing factor to the lack of statistical significance. Future research should include longer scenarios in each condition with more RFI events so that the affects of spatial interfaces on timing and accuracy could be examined more accurately.

The question of whether or not a spatial interface may help users build level 1 SA faster still remains open. Even though users did perform well enough to score significantly higher on one *spatial* SA query in the Outlook condition, it is possible that the SA survey metric was not robust enough to detect a statistically significant difference. That is, if there had been more SA survey questions at the end of each scenario (perhaps six or eight questions), the overall SA survey scores may have produced statistically significant differences.

From a subjective standpoint, the IRVO seems to have been superior at least in terms of perceived mental demand. However, the overall results from the subjective workload measures were statistically inconclusive. One possible reason for these findings may be that the scenarios were well balanced and that the users were equally challenged in each condition (a conclusion upheld by post-test informal interviews). Another reason may be that the IRVO was able to, on average, keep the workload on par with the workload users experienced with the MS Outlook interface. Nevertheless, the fact that participants felt less mentally loaded using the IRVO should be compelling enough to pursue further study of spatial interfaces if for no other reason than to determine why participants feel less taxed by spatial interfaces such as the IRVO, which attempt to exploit the spatial characteristics of information.

Given the pervasiveness of MS Outlook as a software application, this study's findings are promising, considering the novelty of the IRVO interface. It may be possible to further improve the interface to decrease workload by adding physical mnemonic functionality to the IRVO interface, such as the ability to click and drag a box around separate clusters of messages and have them become automatically grouped by subject or date/time received. This type of functionality could perform highly visual reorganization of the data by grouping the message clusters in a hierarchal order such as a pyramid shape or a vertical line. Furthermore, moving the IRVO to a tablet display and placing it on the desk in front of the participant may serve to orient them more effectively, thus facilitating the advantages of a spatial interface.

# APPENDIX A: PROTOTYPE IRVO SCREENSHOT

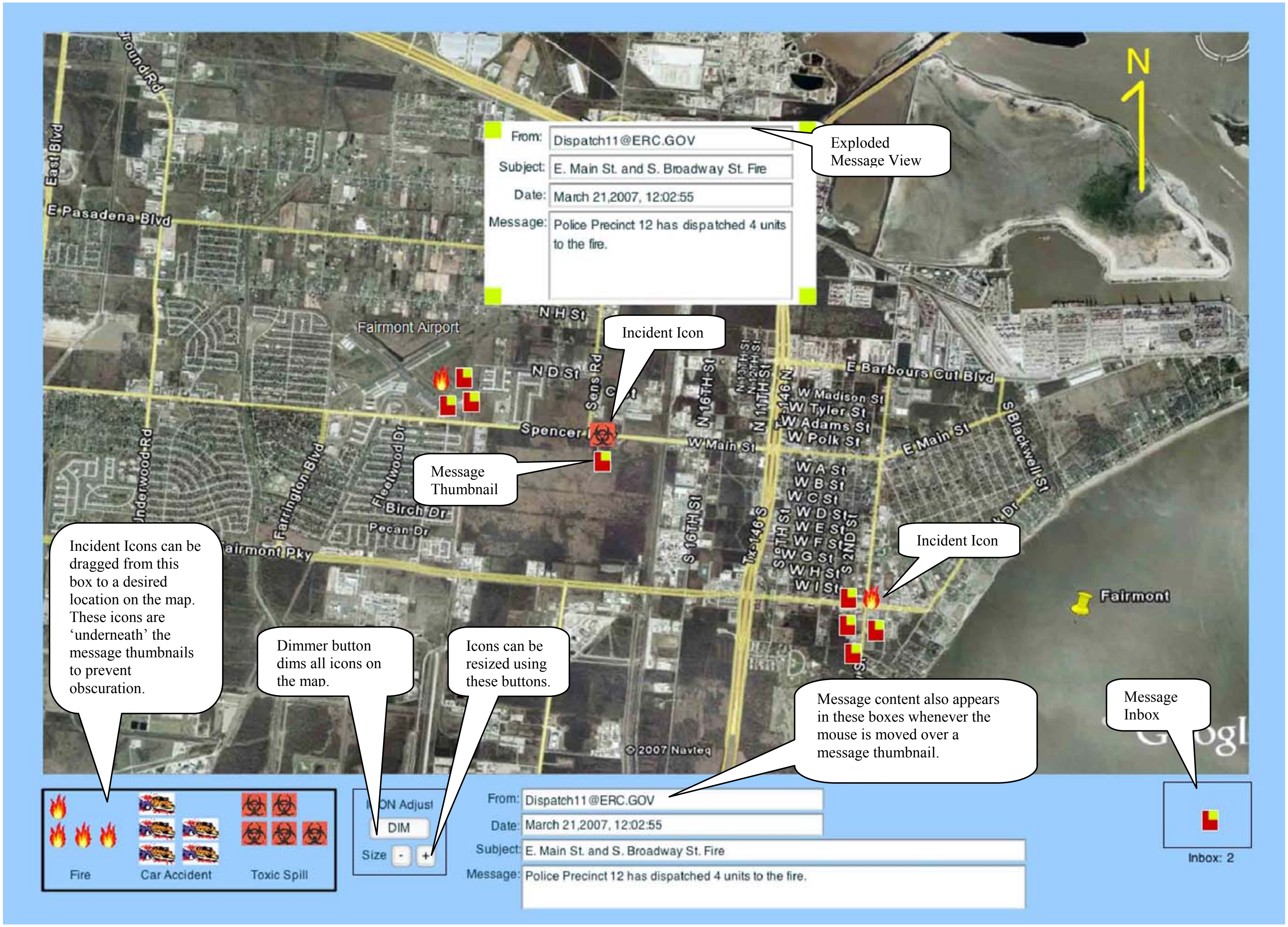


Figure 6 Prototype IRVO Screenshot

# APPENDIX B: NASA TLX

*Note: The electronic version of the NASA TLX metric was administered in each condition.*

**Instructions:** Place an X on each scale at the point that best represents your experience of workload during the scenario you just completed. Marks must be placed inside the box, not on the lines.

**1. Mental Demand:**

How much mental and perceptual activity did the task require of you (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)?

Low Medium High

**2. Physical Demand:**

How much physical activity did the task require of you (e.g., pushing, pulling, turning, controlling, activating, etc.)? This refers to you not your soldier.

Low Medium High

**3. Temporal Demand:**

How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred?

Low Medium High

**4. Performance:**

How successful do you think you were in accomplishing the goals of the task? How satisfied were you with your performance in accomplishing these goals?

Bad Average Good

**5. Effort:**

How hard did you have to work (mentally and physically) to accomplish your level of performance?

Low Medium High

**6. Frustration:**

How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

Low Medium High

**<u>Instructions:</u>** For each of the pairs (e.g., mental demand vs. effort) choose which one of the two items was more important to *your experience of workload* (Circle).

Table 18 NASA TLX Pairwise Comparisons

| | |
|---|---|
| Effort<br>Or<br>Performance | Temporal Demand<br>Or<br>Frustration |
| Temporal Demand<br>Or<br>Effort | Physical Demand<br>Or<br>Frustration |
| Performance<br>Or<br>Frustration | Physical Demand<br>Or<br>Temporal Demand |
| Physical Demand<br>Or<br>Performance | Temporal Demand<br>Or<br>Mental Demand |
| Frustration<br>Or<br>Effort | Performance<br>Or<br>Mental Demand |
| Performance<br>Or<br>Temporal Demand | Mental Demand<br>Or<br>Effort |
| Mental<br>Or<br>Physical Demand | Effort<br>Or<br>Physical Demand |
| Frustration<br>Or<br>Mental Demand | |
| | |

The electronic version of the NASA TLX software for Microsoft Windows can be found at: http://www.nrl.navy.mil/aic/ide/NASATLX.php

# APPENDIX C: PSAQ

**PSAQ**

**1. Please circle the number below that best describes how *hard* you were working during this scenario.**

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| NOT AT ALL HARD | | SOMEWHAT HARD | | EXTREMELY HARD |

**2. Please circle the number that best describes how *well* you performed during this scenario.**

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| EXTREMELY POOR | | AVERAGE | | EXTREMELY WELL |

**3. Please circle the number that best describes how *aware* of the evolving situation you were during the scenario.**

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| NOT AT ALL AWARE | | SOMEWHAT AWARE | | EXTREMELY AWARE |

# APPENDIX D: CONSENT FORM

Please read this consent document carefully before you decide to participate in this study.

Project Title: Applying Augmented Reality to Information Visualization and Management in Crisis Situations

Purpose of the research study: The goal of the proposed research project is to design and evaluate effective information management interfaces based on experimental results. It is allows the Principal Investigator to partially fulfill the requirements for his Master's Thesis.

What you will be asked to do in this study: Volunteer participation in this research project will take place in the UCF College of Engineering's Media Interface and Network Design Laboratory located in Room 311 in Engineering II. Following an informal briefing about the experiment, you will be asked if you are comfortable to proceed. If you are comfortable, you will be asked to perform an information management task as part of fictional scenario involving several emergencies in metropolitan area. You will perform this management task first with one type of software and then with another type. The task consists of organizing incoming emails for the purpose of staying current on the events taking place (for example, the status of fireman responding to a fire). The system will periodically ask you scenario-related questions about the latest information regarding a given event via pop-up survey questions.

Time Required: One session lasting approximately 90 minutes (1.5 hours).

Risks: There will be minimal risk to you during this experiment.

Surveys: There will be one pre-test survey asking for simple demographic background information. Following each software trial, you will be asked to complete 2 post-test surveys requesting information about the degree of mental effort you exerted and how well you think you did during the scenario. You do not have to answer any questions that make you uncomfortable.

Benefits: There is no direct benefit to you from participation in this study. You will receive $5 per half hour completed up to a maximum of $15 for completion of the 90-minute session.

Privacy: Your identity will be kept confidential. Your name will not be used in any report. The recorded data will be assigned a code number. All digital data will be de-identified and stored in a password-protected data file on the principle investigators password protected computer. All non-digital documents, including the informed consent documents, the paper-based pre/post-test questionnaires and a list correlating participant names and code numbers will be stored in a locked cabinet separate from all other study documents for a minimum of three years, after which the information will be destroyed.

Voluntary participation: Your participation in this study is voluntary. You have the right to withdraw from this study at any time without consequence.

More information: For more information or if you have questions about this study, contact

Anthony Costello
College of Engineering
(407)312-9458
mistercostello@msn.com

*Or Faculty Supervisor:*

Dr. Arthur Tang
College of Engineering
(407) 823-3073
khtang@mail.ucf.edu

If you believe you have been injured during participation in this research project, you may file a claim with UCF Environmental Health & Safety, Risk and Insurance Office, P.O. Box 163500, Orlando, FL 32816-3500 (407) 823-6300. The University of Central Florida is an agency of the State of Florida for purposes of sovereign immunity and the university's and the state's liability for personal injury or property damage is extremely limited under Florida law. Accordingly, the university's and the state's ability to compensate you for any personal injury or property damage suffered during this research project is very limited.

Research at the University of Central Florida involving human participants is carried out under the oversight of the Institutional Review Board. **Information regarding your rights as a research volunteer may be obtained from:**

Institutional Review Board (IRB)
University of Central Florida
Office of Research & Commercialization
12201 Research Parkway, Suite 501
Orlando, FL 32826-3246
Telephone: (407) 823-2901

☐ I have read the procedure described above.

☐ I voluntarily agree to participate in the procedure, and I have received a copy of this description.

☐ I am at least 18 years of age or older

_______________________________ _______________

Participant Date

_______________________________ _______________

Principal Investigator Date

# APPENDIX E: DEMOGRAPHIC QUESTIONNAIRE

**Please check the appropriate areas to the left of your answers.**

1. Please check the age bracket that you fall under

_____ 18 – 25 yrs. old

_____ 26 – 40 yrs. old

_____ 41 – 55 yrs. old

_____ Over 55 yrs. old

2. What is your gender?

_____ Male

_____ Female

3. Please check any of the following physical characteristics that apply to you.

_____ Left Handedness (the property of using the left hand more than the right hand)

_____ Right Handedness (the property of using the Right hand more than the left hand)

_____ Ambidextrous (the property of using one hand no more than the other)

_____ Color blind in any way (if yes please describe below)

_____ Wear corrective lenses (reading glasses, bifocals, contact lenses, etc.)

_____ Other (please explain)

4. What is your current job occupation?

_____ Clerical

_____ Engineering

_____ Film/Broadcasting

_____ Skilled Technician

_____ Quality Assurance

_____ Manager/Supervisor

_____ Health Services

_____ Telemarketing/Telecommunications

_____ Student (if student, please list major) Major: ____________________________________

_____ Other (please explain)

5. In general, how do you feel about working with computers?

_____ I don't like working with computers.

_____ I have no strong like or dislike for working with computers.

_____ I like working with computers.

_____ Other (please explain)

6. What is your highest academic degree?

_____ no degrees

_____ High school degree

_____ Trade or vocational school degree (beyond the high school level)

_____ College degree (for example, B.A., B.S., Associate College degree)

_____ Graduate degree (for example, M.A., M.S., Ph.D., Ed.D., M. D., R. N.)

_____ Other (please explain)

7. What is your native language?

_____ English (go to question 9)

_____ Spanish

_____ Other (please name)

8. If your native language is not English, how well do you read English (leave blank if English is your native language)?

_____ Poorly (I have trouble reading documents in English.)

_____ Adequately (I read well enough to get around.)

_____Fluently (I read almost as well as a native speaker.)

_____ Other (please describe)

9. How would you describe your general level of computer experience?

_____ None (I have never used any software applications.)

_____ Low (I have used only one or two software applications.)

_____ Moderately low (I have learned and used between three and ten different software applications.)

_____ Moderately high (I have learned and used more than ten different software applications but have no programming skills.)

_____ High (I have used many different software applications and have some programming skills.)

_____ Other (please describe)

# APPENDIX F: PARTICIPANT INSTRUCTIONS

**Participant Instructions:**
For this research study, you will be responsible for monitoring and organizing incoming messages regarding emergency events in a small city area such as the one illustrated below:


Each message will arrive at random intervals. The messages will include information about emergency events that have occurred around the city such as: fires, toxic spills and/or car accidents.

The messages will provide detailed information such as:

- the exact location of an emergency event
- the status of emergency responders such as Police, Fire or HAZMAT
- the number of emergency units that have been dispatched (or sent) to the event

The following is an example of a message:

> *FROM:* Dispatch41@EOC.COM
> *SUBJECT:* Fire notification
> *MESSAGE:* There has been a fire at the intersection of Main Street and Elm Street

After an initial notification message about an event, such as a fire, additional messages will follow regarding the city's response to that event, such as how many fire and police units were sent to the emergency. Please note that follow up messages for a specific event may not arrive in order. That is, several events may occur simultaneously which can result in follow up messages for each event arriving in random order. For example, you may receive follow-ups to the message above only after first receiving follow-ups to OTHER EVENTS. It simply depends on how fast emergency units are reacting.

It is possible that some types of emergency events may occur more than once. For example, there may be a fire at the intersection of Main Street and Elm Street, followed a short time later by an additional fire on the other side of town. It is up to you to organize the messages so that you know the status of each event.

Your main tasks during the scenario are to **monitor** the incoming messages**, organize** them in a way that is meaningful to you**,** and **maintain awareness** of the latest information regarding each event. You will not be required to forward or respond to any of the messages. A pen and notepad are provided on the desk next to you so that you may take notes.

The **primary purpose** of your job is to answer questions from your supervisor regarding the status of each event. These questions will come in the form of *Requests for Information* (or RFIs). At random intervals during the scenarios, RFI questions will pop up on the screen to your left. You have 90 seconds to answer the questions. A countdown clock will be provided on the screen to assist you in determining how much time you have left.

**IT IS YOUR TOP PRIORITY** to answer these timed questions as soon as possible using the mouse and keyboard in front of you. These questions will only cover information that you collected up to the moment the question is asked. New messages coming in while you're answering your questions will not help you. You may refer to the messages and your notes to assist you in answering the RFI's. After answering the RFI questions, you may continue your task. (DEMO RFI Questions)

At the completion of the scenario, you will be presented with a Scenario Survey consisting of four multiple-choice questions regarding the events that occurred. You will have 60 seconds to complete this task. Please note that you will NOT be permitted to refer to any of your materials while answering the survey questions. The evaluator will turn off your monitor and remove your notes so that you may answer these questions by memory. (DEMO SA QUERIES)

**IRVO Instructions/Familiarization:**

The evaluator will now review the following functions by demonstrating the following:

- How to drag (move) messages
    - left click and drag to move
    - let go of the left button to stop moving
- How to read messages
    - Mouse-over to read the message in the boxes below.
    - Click yellow box
- How to open and close messages
    - Click on the yellow boxes to open and close messages
- How to resize message icons
- How to dim/un-dim all icons
- How to drag (move) event icons
    - Demonstrate how message icons are always on top of event icons
- How icons change color to blue after five minutes
- How the 'inbox' works
    - Note: rollover function works inside the inbox, new messages will cover old ones and appear in the message reader at the bottom of the screen
- Compass indicator is provided in the top right corner
    - Familiarize participant with North, South, East, and West
- Demonstrate RFI (if first time)
- Demonstrate Scenario Survey (if first time)

**<u>Outlook Instructions/Familiarization</u>:**

A color paper map will be provided to you for reference purposes during this scenario.

The evaluator will now review the following functions by demonstrating the following:

- How to drag (move) messages
  - Left click and drag to move
  - Let go of the left button to stop moving
- How to read messages
  - View on right
- How to open and close messages
  - Double click on the message
- How pressing the send/receive button is not necessary
- How to create folders
- Indicate that a compass reference is provided in the top right corner of the paper map
  - Familiarize participant with North, South, East, and West
- Demonstrate RFI (if first time)
- Demonstrate Scenario Survey (if first time)

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