Visualization Methods and User Interface Design Guidelines for Rapid Decision Making in Complex Multi-Task Time-Critical Environments

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VISUALIZATION METHODS AND USER INTERFACE
DESIGN GUIDELINES FOR RAPID DECISION MAKING IN
COMPLEX MULTI-TASK TIME-CRITICAL ENVIRONMENTS

A dissertation submitted in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy

By

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ABSTRACT


Real-world scenarios are complex dynamic systems that are often overloaded with information. Effective performance of these dynamic systems depends on the objects in such systems and the relationship among them. The control of many of these systems is semi-automated. Human operators constantly monitor and control these systems, assess the situation and often make decisions under time pressure. However, this supervisory control paradigm in a dual-task environment can be a very challenging task. Existing interface design methodologies and techniques have not delved deeply enough into defining information displays for complex, dynamic, time-critical, dual-task environments with capabilities for rapid task change awareness and task resumption while continuously maintaining situation awareness.

This research focuses on designing user displays with advanced cueing techniques to support performance in complex dynamic dual-task environments. A primary question addressed in this study is whether visualization methods such as status-at-a-glance displays, interruption recovery tools, and course of action planning tools would assist in maintaining situation awareness, resuming tasks quickly, and effectively perform decision making tasks.

The research examines interface design methods to support supervisory awareness in primary and secondary task situations, rapid assimilation when switching to a secondary task, rapid re-assessment upon return to the primary task or secondary task, a course of action solution explorer for successful mission planning/re-planning, and notification systems such
as alerts to inform operators about interrupting tasks. This research provides a means to realize an “at-a-glance” decision making environment.

The methodology adopted in this research effort used a three-stage process. In stage one, the effect of interruptions on trust and coordination among team members was studied. For stages two and three, the operator tasks and the interface protocols for accomplishing the tasks were designed based on the operator function model. Visual display components were designed to maintain situation awareness, resume the interrupted task scenario quickly, and plan/re-plan course of action for missions and anticipate system status. Multi-modal alert techniques are designed to notify the operator about the interrupting task scenario. The hypotheses related to each stage and the designed components were empirically evaluated using human participants.

Results showed that providing an user interface with status-at-a-glance display and interruption recovery tool and other task resumption cues assists the user in maintaining situation awareness and gain change awareness quickly. It was also found that course of action solution exploration tool assists users in quickly designing a feasible course of action and also allows users to re-plan the course of action based on requirements. The use of alerts helps to inform users about a secondary task that would need their attention.

A primary contribution from this research is defining a set of user interface design guidelines for use on small screen displays for dual-task supervisory monitoring and control scenarios. Other significant contributions include the design of the status-at-a-glance display, along with the interruption recovery tool, mission planning tool, and the evaluation of alert techniques in such complex, dynamic, time-critical environments.
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ACKNOWLEDGEMENTS

I would like to take this opportunity to thank my advisor, Dr. Raymond Hill for his guidance, support, encouragement, patience and counsel. He always set optimistic goals, and offered praise when they were met and understanding when they were not. In addition to his technical guidance, he was also helpful with his excellent writing skills. I consider it an honor to have worked with and known him. I would also like to thank my committee members, Dr. Frank Ciarallo, Dr. Yan Lui, Dr. S. Narayanan, Dr. Edward Pohl, and Dr. Dan Voss for taking their time to serve in my committee and provide their insightful input to this research.

I could not have imagined completing a task this substantial without the moral support and encouragement of my family. I would also like to thank my labmates for helping me during times when solving research issues was difficult and time consuming.
1. INTRODUCTION

In today’s world, many systems are remotely operated or supervised by individuals who are decision makers. The planning, monitoring, and control of many of these systems are supported via visual display units. In some instances, there might be a novice operator at the location with a supervising expert assisting the novice through tele-conferencing or video-conferencing, as required. In other instances, there might not be any human at the system site location; all the operations of the system would be automated and an expert or novice supervising from a remote location could override the automation and manually control the system, when needed. In both cases, the critical factor is information and the assimilation of that information by the operator.

In most dynamic and complex scenarios, the challenges commonly faced by operators are:

a) information abundance and uncertainty,

b) time pressure,

c) varying skill level among the individual decision makers,

d) maintaining situation awareness,

e) mental workload,

f) errors by operators,

g) necessity of rapid decision making, and
(a) necessity of performing multiple tasks.

Information is needed for decision making. When managing a complex system task, decision makers need rapid access to large volumes of information. However, providing large volumes of information could cause information overload. Information overload results in an increase in decision making time (Cohen, 1980) and decrease in decision quality (Chewning and Harrell, 1990; Shields, 1980). In a multi-task scenario dynamic environment, information requirement increases irrespective of whether the tasks are managed separately or concurrently. When task complexity increases, information overload occurs. In such environments, other than information overload, the decision maker is faced with the problem of interruptions. Interruptions could be any unknown event that breaks the operator attention from their initial (primary) task (Corragio, 1990). In order to avoid and overcome conditions of information overload in multi-task scenarios, decision makers require up-to-date and accurate information, presented in an understandable manner, to make quick and appropriate decisions. The need for accurate information is because a high percentage of errors in complex environments such as cockpit, air traffic control, and driving are errors in situation awareness (Endsley, 1999). The decision maker could be making a correct decision for the presented information, but the information might not be the latest, causing errors. In this research, the multi-task scenario designed is a dual-task scenario, with each task scenario consisting of multiple tasks.

In a dual-task scenario environment, there is a primary task and a secondary task (interrupting task or interruption), which are not necessarily related to each other. The operators monitor and control the tasks from a single small screen visual display unit. When the operators are handling one task, the other task is not shown to them. Often the operators
must switch from the primary task to the secondary task thus interrupting the primary task that they were performing. In dynamic environments, events do not pause because of interruptions. The interrupted primary task scenario continues to evolve and hence information continues to change in it. The operator must assimilate the information in the secondary task scenario and perform the required operations to support the task goal. After completing the secondary task, the operator must return to the primary task, re-assess the situation, and resume operations for that task. Under such circumstances, especially when the operators resume their interrupted task, operators may experience a loss of situation awareness and an increase in mental workload.

In real-time dynamic environments, an “at-a-glance” display philosophy provides a means for decision makers to rapidly assimilate requisite information and maintain situation awareness. This research focuses on extending this “at-a-glance” concept to dual-task environments and defining user interface design guidelines and other visualization methods to improve monitoring and control and hence operator performance in time critical, dynamic environments in which operators must quickly switch among tasks. Other visualization methods include 1) interruption recovery tool and supportive visual cues to help the operators in gaining change awareness and effectively resuming tasks after interruption, 2) course of action solution explorers to assist the operators in planning/re-planning missions based on interpretation of future system status, and 3) a multi-modal alert system to notify the operators about an the interrupting secondary task that requires their attention.

This research involved three separate experiments. Experiment 1 studied the effect of interruptions on trust and coordination issues in virtual teams. Using the findings from experiment 1, user interface design guidelines were developed, leading to the design of two
interfaces: a baseline interface consisting of conventional user interface components and an advanced interface consisting of newly designed visualization components. A scenario-based design approach was followed. Experiments 2 and 3 examined the effect of new visualization components and alerts on operator situation awareness, task resumption capability, and change awareness.

An important significance of this research is that it focuses on the design and implementation of small screen user interfaces (17-inch display screen) that allows and assists a single human operator to be able to perform supervisory monitoring and control tasks in a dynamic complex time-critical dual-task scenario where both the primary and secondary task scenarios are information rich and have domain similarity. At any instant, only one task scenario can be viewed on the screen and controlled by the operator while the other scenario not viewable, would continue to change.

The primary contributions of this research include the definition of a set of user interface design guidelines for dynamic time-critical dual-task environments, design of status-at-a-glance display to maintain situation awareness at all times and quickly assessing the situation when switching tasks, obtaining change awareness and resuming tasks quickly after interruption using the ‘Elapsed Events Image Viewer’, and design of a solution exploration tool that allows planning and re-planning course of action. Another significance of this research includes studying the effect of interruptions on trust and coordination between members of a team who are geographically distributed.

This dissertation document is divided into eight chapters. Chapter 2 presents the research background providing reviews on decision support systems, information visualization, experiments conducted in time critical scenarios and dual-task environments.
Chapter 3 discusses research issues in dual-task environment domain and lays down new avenues for research. Chapter 4 presents the research methodology used to address and overcome some of the research issues described in chapter 3. The research methodology is a three phase experimental-based methodology. The research questions and the user interface components that were designed and developed in the research are explained. Chapter 5 describes the phase one experiment conducted to understand the effect of interruptions on team performance. Chapter 6 discusses the phase two experiment and results that were obtained to understand the effect of visual displays on maintaining situation awareness and assistance in recovery from interruptions. Chapter 7 describes the final, phase three experiment on the effect of alerts on user performance in dual-task environments. Chapter 8 describes the research contributions towards rapid decision making in time-critical multi-task environments.
2. RESEARCH BACKGROUND

This chapter provides background information on the research. Topics include decision support system, information visualization, status-at-a-glance methodology and human performance concepts such as attention management and situation awareness. The intent is to determine how to develop a human computer interface so that humans can effectively multi-task, even in complex, dynamic domains.

2.1 Decision Support Systems (DSS)

A key to making intelligent decisions in demanding environments is the correct interpretation of data. Due to the volume or complexity of the data, the process of understanding and interpreting such data is often very time consuming. Decision support systems (DSS) enable the user to make fast, responsive decisions based on all the necessary information. The term DSS was first coined by Keen and Scott-Morton (1978).

Ceric (1997) summarizes DSS characteristics as being able to:

- "Assist the user in semi-structured decision tasks,
- Support managerial judgment,
- Improve the effectiveness of decision making,
- Be used by non-computer specialists in an interactive manner,
- Combine use of models with databases, and
- Adapt to the decision-making approach of the user".
Decisions associated with a problem can be determined instantaneously or by first generating a set of decision alternatives and then choosing the best alternative according to some criteria. Most real world problems are multi-criteria problems. In multi-criteria decision making (MCDM), decision makers are faced with several decision alternatives and use a variety of criteria for evaluating and comparing these alternatives. MCDM can be interpreted as an incremental individual learning process about a decision situation (Angehrn, 1991). However, such an approach cannot be followed in certain problem-solving environments. For example, workers in power plants or supervisors in command and control situations are often faced with decision-making tasks under time pressure while monitoring and controlling computer-based systems.

For any scenario, decision makers follow some procedure in an attempt to solve their problems. Some of the important steps are to: gather information related to the situation, organize the information, select from the information, and review what information is required to continue to the next phase of problem solving. However, in time-constrained scenarios, providing all information to the decision makers in all instances, and then asking them to filter the necessary information according to the demands of the situation is not a good problem-solving strategy. Furthermore, actual decision environments have time-varying goals and involve incomplete and uncertain information.

Mason and Mitroff (1981) argue that one of the most difficult problems in complex decision situations is the gathering of appropriate information and properly assessing the situation. For rapid situation assessment and decision making, a necessity in time-pressured high stress environments, it is important to make decisions quickly. Under such conditions, Mason and Mitroff (1981) have identified three types of errors that can occur in assessing a
situation: Type I errors – errors that result from incorrectly assessing that there is a problem where there is no problem. Type II errors – errors that result from incorrectly assessing that there is no problem where there is a problem, and Type III errors – errors that result from correctly assessing that there is a problem, but incorrectly identifying the nature of the problem.

Decision support systems must be designed considering the skill level of the users of the support systems. Klein et al. (1993) observed that expert decision makers do not generate or evaluate alternatives, but only assess the situation. After a situation has been assessed, the reaction strategy and the final decision process based on situation awareness are almost instantaneous. It has been widely accepted that situation assessment centered decision making, also referred to as recognition primed decision making, is an appropriate form of human decision making under time-critical situations (Endsley, 1993a; Endsley, 1995; Klein, 1989a; Klein, 1989b). However, individuals who are novice to an environment need sufficient training to make rapid and correct decisions. The DSS should be designed to assist people with different skill sets, from training the novice through helping the expert make fast and effective decisions.

In any complex problem, there is no paucity of data. As decision makers begin to explore a problem to resolve it, more data is obtained. Decision makers need to integrate raw data and obtain sensible information that can be utilized for problem solving. Assisting the decision maker in data integration and properly visualizing the situation is a key DSS task. With advancement in computing technologies, new computer software or applications are being developed to help integrate the raw data and help the decision maker to visualize and analyze the data and collectively generate necessary information.
2.2 Information Visualization

Although many modeling and analytical techniques exist for decision making at different levels in an organization, visual information representation at each level helps in making faster decisions. Visual aids are predominantly used in the identification, evaluation, and prioritization of criteria for a decision problem as well as in evaluation and selection of alternatives for decision selection.

Card et al. (1999) define information visualization as

“The use of computer-supported, interactive, visual representations of abstract data to amplify cognition.” (pg. 6)

Based on the nature of the problem, visualization tools can be used to assist in decision making. Some information visualization tools and techniques that are used for collaboration and decision making are desktop computers, handheld devices such as Personal Digital Assistants (PDA), electronic meeting rooms, electronic brainstorming, whiteboard, desktop video conferencing, electronic mail, instant messaging interfaces, Microsoft Net Meeting, large format displays, virtual environments, shared desktop displays, geographic information systems (GIS), geo-visualization tools, and web services. GIS support multimedia tools such as image and sound manipulation capabilities along with linkages to charts, diagrams, and tables to enhance information presentation.

Lohse et al. (1994) determined eleven categories of visual representation. They are: graphs, tables, graphical tables, time charts, networks, structure diagrams, process diagrams, cartograms, icons, and pictures. Graphs are used to depict quantitative information using position and magnitude of the geometric objects. Some common graph types are scatter plots, bar charts, pie charts, histogram, and response surfaces. Tables involve the arrangement of
numbers, words, or symbols to exhibit some relationship in a compact format. Time charts such as Gantt charts are used to display temporal data. Network charts such as flow charts, decision trees, PERT charts are used to show the relationships between the different components in a scenario. Both structure and process diagrams are used to express spatial data. While structure diagrams are static descriptors of physical objects, process diagrams illustrate the dynamic and continuous relationship among the physical objects. Maps are symbolic representation of physical geography. Cartograms are spatial maps that show quantitative data such as flow maps. Icons are used for visual representation in cases where the users of the particular system are familiar with the meaning of the icons. Pictures are photo-realistic images of a physical object or scenes that are extensively used in scenarios equipped with GIS.

Over the past few decades, many visualization tools have been designed and developed to solve the ‘too much data, too little display area’ problem; the presentation problem (Spence, 2001). Most computer-based information systems provide a small window through which an information space is viewed. This gives rise to problems

a) in locating a given item of information,

b) in interpreting an item, and

c) in relating it to other items if the item cannot be seen in its full context.

Woods and Watts (1997) have documented, based on field studies, that large networks of displays, viewable through a limited screen space, can place new mental burdens on users. This limited screen space constraint is known as the keyhole-effect where only a small fraction of the entire process evolving in a particular scenario is revealed on the screen.
at any instant. The critical challenges in designing large display networks revolve around how to help users

a) avoid getting lost in the large space of possibilities,

b) find the right data at the right time as tasks change and activities unfold,

c) integrate interrelated data that spreads across different kinds of display frames, and

d) avoid becoming focused on interface management in lieu of focusing on the task.

Three trends in information visualization have emerged to address problems associated with presenting large networks of displays of raw data (Woods and Watts, 1997):

- Information animation: Static values that display the current state of the system are enhanced with the computer medium allowing developers to emphasize change, activities, and events that extend into the future as well as the past.

- Integrated representations: Each data type in a system can have an independent display. In such cases, the user must mentally combine all displays to understand the overall system status and make decisions. More recently, developers are involved in designing more coherent views into some system. Such views integrate individual data type displays and also show the relationship among these elements in the system. The user can understand the system status much easier through the visual displays and hence reduce the mental workload.

- Coordination of multiple views: Systems are developed with multiple display views so that the users can carry out their work more actively. For instance, in air traffic control (Mavoian, 2002), both a two-dimensional and a three-dimensional
map of the scenario are provided to the controllers so that problems can be identified and solved quickly and accurately.

Many concepts have evolved to support the process of visualizing the underlying data and for accessing large sets of information through a small display window (Card et al., 1999). Due to the growing number of presentation techniques, Leung and Apperley (1994) have categorized the visualization techniques as distortion-oriented and non distortion-oriented presentations.

Distortion-oriented techniques allow the user to examine a local area in more detail on a portion of the screen, and at the same time, present a global view of the entire scenario so as to provide an overall context to facilitate navigation. These techniques are gaining popularity because of the availability of low cost, high performance workstations (Leung and Apperley, 1994). Some distortion-oriented techniques are:

- **Bifocal Display (Spence and Apperley, 1982):** The original version of the bifocal display was a one-dimensional representation of a data space whose area exceeded that displayable on the screen. It was developed for use in office automation environments. The one-dimensional display involves a combination of a detailed view and two distorted side views, with information on either side of the detailed view compressed in the horizontal direction. Although the technique provided spatial continuity between the regions, a disadvantage was the discontinuity of magnification between the detailed view and the distorted view. The bifocal display was extended to a two-dimensional representation format for topological networks such as, for example, the London underground map (Leung, 1989). In this approach, the visual region is subdivided into nine regions with a
central focus region. The other eight regions are de-magnified according to their position with respect to the central focus region. In the one-dimensional display, there was discontinuity of magnification between the different views. In order to avoid such a condition, in two-dimensional displays, the de-magnification factor is maintained identically in both the ‘x’ and ‘y’ directions; the regions around the central focus are not distorted, they are only reduced in size.

- Fisheye View (Furnas, 1986): The Fisheye View is a presentation method for information having a hierarchical structure. The primary theme of this technique is called ‘thresholding’. Each information item in the hierarchical structure is given a number based on its relevance and a second number based on the distance between the information item under consideration and the point of focus in the structure. A threshold value is then selected and compared with a function of these two numbers to determine what information is to be presented or suppressed. The function is called the degree of interest (DOI) function, which determines for each point in the information hierarchy, how interested the user is in viewing that point with respect to the current focus point. Thresholding causes the more relevant information to be presented in more detail, and the less relevant information is presented in a more generalized form. Hollands et al. (1989) present a subway network using the Fisheye View concept and using a simple scrolling view. The two interfaces were compared based on users’ performance on three different tasks: routing task, locating/routing task, and an itinerary task. The Fisheye concept used by Hollands et al. (1989) had more in common with the Bifocal display than Furnas’ DOI function. The symbols displayed in the Fisheye
View interface were smaller than in the scrolling view, and thus contradicting the concept of Furnas’ DOI function (Leung and Apperley, 1994). Another variant of the fisheye view concept was proposed by Mitta (1990) for the presentation of aircraft maintenance data. Mitta used a multiple-focus-point version of the Furnas’ concept along with the information suppression technique. In each of the Fisheye views, certain aircraft components were suppressed so that the user could focus attention on the parts that were displayed on the screen. Sarkar and Brown (1994) extended Furnas’ Fisheye concept and developed a mathematical formalism for graphical application of this concept. Two implementations were proposed: one on a Cartesian coordinate transformation system and the other based on a polar coordinate transformation system. These transformations provided distortions in two dimensions. Sarkar and Brown (1994) introduced information magnification on a third dimension, based on the a priori importance (API) concept of Furnas. API is the number assigned to each vertex in a graph representing its relative importance in a global structure. Based on the API of a vertex on a graph, three separate functions were computed to determine size, visual worth, and the amount of detail to be shown for the vertex. These functions provide an information suppression and enhancement mechanism to generate an effective Fisheye View. This technique can be widely used for the display of information that is multi-layered and organized in a hierarchical tree or network structure.

- Perspective Wall (Mackinlay et al., 1991): In the Perspective Wall technique, the required information is visualized by combining detailed views and contextual
views of the scenario. Consider a display area having a right side panel, a middle panel, and a left side panel. The side panels are at an equal angle, \( \theta \), to the middle panel. In this concept, the distorted views of the out-of-focus regions displayed on the two side panels are de-magnified directly proportional to the distance from the viewer. However, researchers found that there is a discontinuity in the magnification at the points where the two side panels meet the middle panel, depending on the angle; the greater the angle, the higher the discontinuity. The view generated by the perspective wall is dependent on the length of the wall, width of the viewport, \( \theta \), and the size of the central region. With the width of the viewport fixed, as \( \theta \) is increased, the viewer must be positioned further away from the wall. The position of the viewer determines the projection of the two side panels on the visual plane. It is believed that the perspective wall provides a three-dimensional feel of the visual region. However, this effect is accomplished by wasting some display area at the corner areas of the screen, violating an important objective of distortion techniques which is to maximize the utilization of the display area. The Document Lens (Robertson and Mackinlay, 1993) technique was developed to overcome this disadvantage of the Perspective Wall.

- **Document Lens (Robertson and Mackinlay, 1993):** The Document Lens is a 3D visualization technique for understanding paper documents by presenting the pages of the document in a rectangular array on a large table representation where the overall structure and the distinguishing features can be seen. This allows the user to quickly focus on a part of the presentation at a desired magnification while retaining the context of the entire document.
• Table Lens (Rao and Card, 1994): The Table Lens is a methodology for visualizing and comprehending large data tables. The data content is displayed along rows and columns with labels at the row and column edges, similar to tables. This approach is effective in providing faster identification and interpretation of the meaning of information in the cells. The Table Lens combines symbolic and graphical representations into a single view that can be adjusted by the user. The visualization uses the Fisheye technique allowing the display of important label information and the use of multiple focal areas. In this visualization, the distortion in the x and y directions are independent and hence the rows and columns are not bent by the distortion. This feature allows the display of labels and multiple focal areas. The Table Lens also contains many manipulation operations for controlling the focal areas. These operations include zoom which changes the space allocated to the focal area without changing the number of cells, adjust which changes the number of cells viewed in the focal area without changing the focal area size, and slide changes the location of the focal area on the display. The Table Lens uses many types of graphical representations for content display in the cells. The presentation type in the cells varies based on factors such as value, value type, region type, cell size, user choices, and spotlighting.

Non distortion-oriented techniques have been used for the presentation of textual data and in a number of graphical applications. Familiar approaches involve displaying a portion of the information and using scrolling to access the remaining sections of the information. Another approach is to represent the data in a special presentation method such as a Tree-
Map (Shneiderman, 1992) or a Cone Tree (Robertson et al., 1991). The motivation behind the development of the Tree-Map technique (Shneiderman, 1992) was to better represent storage space on hard disk drives from the standpoint of a multi-level directory of subdirectories of files. This technique makes use of the available display space, mapping the entire hierarchy onto a rectangular region in a space-filling manner. Traditionally, a tree structure is represented with a root node at the top and children nodes below the parent node with lines connecting them.

Tree-maps are designed from these tree structures as a two-dimensional space filling representation in which each node is represented as a rectangle whose area is proportional to the node size. On hard drives, this visualization approach allows users to rapidly note the large files and identify them for possible deletion if the hard drive is filled.

The Cone tree (Robertson et al., 1991) is another technique for representation of hierarchical information. It is a three-dimensional representation of the hierarchy to visualize the entire structure and also make use of the available space. The Cone tree was designed to replace the traditional two-dimensional representation of a hierarchy because it would not fit the screen and the user would have to scroll through the layout or use a reduced image size of the structure. In the Cone tree approach, the parent node is located at the apex of the cone with all its children nodes located around the circular base of the cone. Any node can be brought into view by clicking on it and rotating the tree. Some applications of Cone trees are representation of directory structures, organization charts, and company operating plans.

Researchers have also tried to enhance the ability of users to find specific information by dividing the total information space into portions which can be displayed and to provide hierarchical structure to these separate portions of data. In this approach, as one moves down
the hierarchical structure, more detailed information about a smaller area of the information space is given. However, one of the main weaknesses of the non-distortion oriented technique is the lack of adequate background for the user to support navigation of large scale information spaces.

Other visualization tools and concepts that have been developed include:

- **InfoCrystal** (Spoerri, 1993): This is a high level information retrieval tool that can be used both as a tool for visual exploration and as a tool for graphically formulating queries to help users search for relevant information. It visualizes all possible relationships among N concepts.

- **VisDB** (Keim and Kriegel, 1995): This is a system that supports the query specification process by visually representing the results. Each database item is represented by one display pixel. All pixels are finally arranged and colored to indicate the relevance of the item to a user query.

- **TennisViewer** (Jin and Banks, 1997): The Tennis Viewer is an interactive system that provides the user with an interface to visualize dynamic sports information, such as a tennis match. The tool uses tree structures to organize information on a tennis match. A tennis match consists of several sets. Each set consists of several games. Each game consists of several points. Each point consists of one or two services with each service consisting of several strokes. These levels of hierarchical information can be organized as a tree with the bottom nodes being the strokes and the top node being the match. In tennis matches, competition is an important property – two players compete against each other to claim a higher level of the match hierarchy. The match playing process is a bottoms-up tree-
building process where each player tries to build his own tree up to the next level. When the player wins a service, he claims the higher node – a point node. When the player wins the last point, the player wins the higher node – the game node. As the player wins the set, the player moves up their tree and claims the set node and finally whoever wins the match, claims the match node. Bringing together the two trees built by the two players playing against each other in the match forms a competition tree.

- Magic lenses (Bier et al., 1993): Magic lenses are used to reveal the information at the lower levels of the hierarchy and allows for deep zooming. Magic lenses (Bier et al., 1993) are based on the same principle as reading a newspaper with a magnifying lens to enlarge the size of the text on the paper. In the context of information visualization, the magic lenses are placed over the area of interest in the display and more detailed information about that area is received by the zooming-in or magnification of the lens.

- Lifelines (Plaisant et al., 1996): This is an environment for visualizing summaries of personal histories and other types of biographical data. Lifelines reduce the chances of missing information, facilitate spotting trends, and streamline access to details. Line color and thickness illustrate relationships among data while rescaling tools and filters allow users to focus on missing information.

- Pad++ (Bederson et al., 1996): This is a zooming graphical interface as an alternative to traditional window and icon-based approaches to interface design. It supports creation and manipulation of multiscale graphical objects, and navigation through the object space.
Card et al. (1999) summarize the different types of data for which the above mentioned information visualization techniques and related tools have been used:

a) statistical and categorical data (census, health, labor, manufacturing process supervision, bank accounts),

b) digital libraries (books, films, videos, maps, manuscripts, journal articles, world wide web pages),

c) personal services (travel information on airlines, consumer comparison of products, classified advertisements for home and jobs),

d) complex documents (biography, annual report, software module),

e) histories (patient, student, employment, sales history, stocks, project management),

f) classifications (hard disk data directories, family tree, organization charts), and

g) networks (telecommunication connections, highways, pipelines, electronic circuits, organizational relationships).

Research has shown that information visualization has also helped in collaborative decision making. Visualization methodologies have ranged between virtual reality environments, displays with numeric and graphical representations, large screen displays, and 3D modeling techniques. Some of the environments in which such visualization methodologies have been successful are in Air Traffic Flow Management (Mavoian, 2002), highway projects (Liapi, 2003), CAVE6D (Park et al., 2000), emergency management operations (Rauschert et al., 2002), and command and control (Lehner et al., 1997).
2.3 Attention Management

In a complex environment, when there are many tasks and when a number of parameters are changing simultaneously, it is difficult for the human to maintain high performance efficiency. There can also be instances when the individual has a slight to complete lapse in attention. The duration of this lapse in attention will differ depending on the nature of distraction. Researchers have classified attention into selective attention and sustained attention, further classifying selective attention type into divided attention, and focused attention (Schneider et al., 1984).

In selective attention, the subject will selectively attend to some task, or aspects of a task, in preference to others (Kahneman, 1973). Studies have shown that subjects exhibit reduced performance when they try to simultaneously accomplish an increased number of tasks (Kahneman, 1973). Other studies on focused attention examine the ability of subjects to reject irrelevant information and try to concentrate on one kind of information. Studies conducted by Eriksen and Eriksen (1974), Stroop (1935), and Shiffrin and Schneider (1977) have shown the inability of subjects to reject irrelevant information.

In the Stroop (1935) Color-Word Interference Test, the task required the subjects to state out aloud (talk aloud) the color of the ink in which a color name was printed. For example, if the subjects were presented with the word ‘red’ printed in green ink, they had to talk aloud - ‘green’. The subjects had difficulty ignoring the color implied by the printed word when trying to vocalize the color of the ink. The vocal reaction time was much slower when the printed name was incompatible with the ink color than when the printed name was compatible. The author concluded that since subjects consistently responded to the word red by vocalizing ‘red’, this automatic process would interfere with orally identifying a different
ink color detected visually. When information is provided in the form of visual images such as symbols or graphs or color codes, the designer must make sure that similar incompatibilities are avoided. In environments such as command and control, issues due to color can generate potentially catastrophic effects.

In sustained attention tasks, attention is directed towards one or several sources of information over a long continuous time period so that subjects can respond to small changes in the presented information. Researchers describe these changes in the state of the display being monitored as signals. Davies et al. (1984) note that, traditionally, individual performance in sustained attention situations can be assessed in terms of a) detection or hit rate, which is the proportion of signals correctly detected, b) commission error or false alarm rate which is the number of occasions on which a signal is reported when actually, no signal is presented, and c) the detection latency defined as the time taken to report the presence of a signal. During the course of a task, as time increases, typically, there is a decrease in detection rate and increase in detection latency.

2.4 Information Uncertainty

In military command and control, commanders want a clear, concise, and accurate assessment of the current situation. Unfortunately, when considering combatant forces, there is always uncertainty about where everyone is located, what are their capabilities, and what is the nature of their intentions. Alberts et al. (2002) surmise that commanders in war often do not have a timely and accurate picture of their own forces. In such situations, they also would not have confidence in their knowledge of the enemy. According to Moray (1984), an individual’s task in any system is to know the system and to respond in whatever way the
system requires. Often, there is some problem in carrying out even simple tasks. Some of the individual’s problem might be due to uncertainty, poor communication, or lack of shared knowledge. Parsaye and Chignell (1988) regard uncertainty as a three-step process. In step 1, inexact information of basic events is provided, in terms of rules defined in likelihood values. In most cases, these basic events are interrelated. Therefore, in step 2, the information from the events in step 1 are combined to obtain a global value for the system. Many methods, such as Bayesian probabilities, Dempster-Shafer theory of evidence, certainty factors, and fuzzy sets are used to integrate the information. In step 3, inferences are derived from the inexact knowledge obtained in the previous two steps.

In industrial systems, the causes of uncertainty have been divided into two classes: exogenous and endogenous. Exogenous uncertainty describes factors that cannot be controlled by the system operator. These factors arise from the dynamics of the system such as temperature and pressure fluctuations. Endogenous uncertainty describes factors within the control of the system operator. Under exogenous uncertainty conditions, the system operator might not be able to predict the future state of the system for an indefinite time period even if the person knows the current values of the system parameters. Endogenous uncertainty includes factors such as forgetting, misreading instruments, failure to make an observation, failure to weight evidence correctly, and psychological factors related to reduced accuracy on the part of the human to keep track of information initially acquired.

There are three basic methods of representing uncertainty: numeric, graphic, and symbolic. A numeric method is the most common method of representing uncertainty. For example, 0 is often used to represent complete uncertainty, while 1 or 100 is used to represent complete certainty. Although such representations seem very easy to use, Parsaye
and Chignell (1988) found that people tend to interpret and use numbers based on their own past experiences (termed cognitive biases); they do not use the numbers according to the requirements of the current scenario. In the case of a graphical representation, people, especially experts, use horizontal bars or scales to express their confidence or uncertainty associated with events. Turban and Aronson (1998) noted that some experts did not have experience using graphical scales and hence, the accuracy of interpretation was relatively lower compared to numerical scales. Most experts prefer non-quantitative techniques, such as ranking over graphic or numeric representations, because the techniques are more symbolic in nature.

There are two common types of ranking: ordinal ranking which is the listing of items according to their order of importance, and cardinal ranking in which ranking is complemented with numerical values. However, according to Turban and Aronson (1998), when ranking a large number of items, users tend to become inconsistent in their rankings. The analytical hierarchy process (AHP) is a methodology to reduce the problem of inconsistent ranking with large datasets. Saaty (1982) describes AHP as a flexible model that allows repetition or iteration over time helping decision makers to refine their judgement for solving various unstructured problems. There are three principles underlying the AHP model: a) hierarchy structuring which is the breakdown of the problem into separate elements, b) priority setting which is the ranking of elements in the problem according to their relative importance, and c) logical consistency which is the process of ensuring that all elements are grouped logically and ranked consistently.

Another form of graphic representation are influence diagrams. Influence diagrams are graphic representations of a model used to assist in model design, development, and
understanding. These diagrams are called influence because of the dependency of a variable or component on the levels or states of another variable or component. They are often used in conditions of decision theoretic reasoning (Gottinger and Weimann, 1995). There are many ways to express uncertainty numerically. Most often, decision makers use a Likert scale approach, which usually gives five options to express their opinion. For example, an individual may be asked to assess a website on a five-point scale: worst, bad, neutral, very good, and excellent. Symbolic representation methods are often combined with numbers or converted to numeric values. It is also customary to give a Likert scale weight of 1 to 5 to the five options.

Even if accurate or certain information about the status of all objects in a scenario is provided, it is possible that later the operator may not accurately remember what was observed and hence will be unsure of the system state. The operator will have to again pay attention to all the objects parameters they had monitored in the past. In a collaborative scenario, the team of operators must decide which operators will examine which set of objects, how long the objects should be monitored, what object parameters should be monitored, whether the new information about the objects are reliable, how to combine the new information with existing information already possessed by the operator, what parameters of the objects must be shared with other operators, and how to use the new information to make future decisions. In all the above-mentioned decision tasks, it is important that the decision makers be attentive to information, which might be certain or uncertain. If the scenario is monitored and controlled by a single individual operator then, except for sharing information, they perform all decision tasks. The responsibilities of the individual operator are increased and they have to be situationally aware of the entire system.
2.5 Situation Awareness

Situation awareness (SA) is defined as being aware of what is happening in the environment (Endsley, 1995). It is an individual’s knowledge of a situation upon which they decide or react, when required (Endsley, 1995).

Formally, situation awareness is defined by Endsley (1988) as

“The perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future.”

Endsley (1995) categorized three levels of situation awareness:

1) Level 1 SA: awareness of relevant elements and details of a situation,
2) Level 2 SA: understanding of the situation, and
3) Level 3 SA: prediction of the outcome of the situation in the near future.

In achieving SA, the first step is to know the different elements in the environment, and to perceive the status, attributes, and dynamics of these elements. This constitutes Level 1 SA. Level 2 SA involves understanding the relationship between these elements and their significance with respect to the user’s tasks and goals. Level 3 SA is the highest level of situation awareness where the user, based on knowledge obtained from Level 1 and Level 2 SA and comprehension of the situation, predicts the action and status of the relevant environmental elements in the immediate near future.

SA is context dependent. Awareness depends on the specific circumstances defining the situation. Given a particular scenario from a domain, the elements of awareness that are required are (Pew, 2000):
• current system state,
• predicted state in the near future,
• information and knowledge required for current activities,
• activity phase,
• list of current goals
  - currently active goal, tasks, sub-tasks,
  - time, and
• information and knowledge required for near future situations.

Along with situation awareness, there are other elements of awareness that the individuals in an environment must possess:

• mission goal awareness, which is knowing the current stage of a mission and the active goals that must be satisfied,
• system awareness, which is knowledge about the method of operation of the devices or programs used in the environment,
• resource awareness, which is required to keep track of current state of available resources that would be both physical and human resources, and
• crew awareness, which is the sharing of their information by each crew member among all other team members and also their interpretation of current system events.

An individual’s SA is not constructed by putting all information into a system. SA is built from knowledge obtained directly from the real world (user experience), and from technical systems that acquire information and present it to the individual through different visual displays (user interfaces). These sources of information together help a person build
their SA model about the environment. Endsley and Jones (1997) have noted that given all these information sources only a small portion of all this related information is accurately acquired by the individual. During the entire process, there might be instances when there is a loss of information due to both the system design and the display interface design.

SA is largely influenced by the way information is presented to the user through the interface. SA is impacted by the amount of information that can be acquired, how accurately the information can be acquired, and to what degree the acquired information is compatible with the needs of the individual. SA has long been a concern in human interface design (Endsley and Jones, 1997).

Endsley (1995) put forth a set of guidelines to create a SA-oriented system design:

1. The extent to which visual displays directly show information necessary for meeting Level 2 and Level 3 SA requirements will impact SA.
2. Presenting information in terms of the individual’s goals will impact SA. Organizing information in such a way that it can be easily found and assists the individual in making important decisions associated with the goal is essential.
3. In complex systems, user mental models are key features in achieving higher levels of SA. In any domain, the cues required for activating the user mental models must be determined and made a part of the interface design.
4. Design features such as color and flashing lights should be avoided for non-critical events as they may divert the attention of the individuals from their current goal-directed tasks.
5. Global SA, which is the overall situation in the scenario, must be provided along with detailed information about the current goal to all users. Global SA also helps
in interpretation of future events. System designs that automatically filter the information shown on the display to match only the current goals should be avoided.

6. Preventing automatic filtering of information can lead to information overload. SA can benefit and information overload can be prevented by filtering all information not related to the global SA needs of the current scenario, and to reduce the number of lower-level data by integration into higher level meaningful information.

7. Successful projection of future events and states of the system that benefit Level 3 SA depends on a good user mental model. System generated support in this issue helps novice users.

8. In complex multi-task systems, sharing attention between multiple tasks and sources of information is essential for maintaining SA and can be achieved by designing systems that support parallel processing of information. For example, a system built with audio signals or cues to augment visually overloaded displays can be beneficial to users in completing tasks effectively.

2.5.1 Workload

Situation awareness is also affected by workload (Endsley and Jones, 1997). Workload is defined as the amount of work that an operator or team of people perform during a specified time period. A formal definition of workload is given by Stein (1998):
“The experience of workload is based on the amount of effort, both physical and psychological, expended in response to the system demands (task load) and also in accordance with the operator’s internal standard of performance.” (Stein, 1998).

Workload varies with task difficulty and complexity. Generally, workload can be categorized into low, medium, and high level conditions based on the nature and number of tasks, their complexities, and the amount of information processed within a given time (Endsley and Jones, 1997). As the nature of tasks changes, and the amount of information processed increases along with an increase in the number of tasks and their complexity, there is an increase in workload (Endsley and Jones, 1997). Under low to medium workload conditions, SA is independent of the workload (Endsley, 1993b; Endsley and Jones, 1997). However, at high workload conditions, there will be a decline in SA (Endsley, 1993b; Endsley and Jones, 1997; Endsley and Rodgers, 1998). If there is information overload and heavy task load, SA will be affected either because of an inability to handle all the incoming information or due to incomplete integration and perception of information (Endsley, 1993b; Endsley and Jones, 1997; Endsley and Rodgers, 1998). System designs that cause information overloading on the individuals can affect SA. A high workload problem scenario might become impossible to solve if the information is not properly presented as required. Too much information can cause individuals to lose track of the information that is immediately required, again resulting in increased information overload and an increased workload thus affecting SA (Endsley and Jones, 1997).

In a real-time environment, SA is an important element but difficult to empirically assess. Information and status updates are required to support all tasks currently in the process queue of a scenario as well as those anticipated in the near future. Some information
is inherently dynamic. With changing priorities, information needs also change. Most of the information provided is simply raw data. Keeping up with the pace at which such pieces of information or raw data is delivered is not the requirement. The raw data must be interpreted into meaningful information and then related to the other available information and the task requirements. Adam et al. (1995) elaborate on this issue. The next section discusses a visualization method, termed status-at-a-glance display, that is being used by researchers to improve SA and speed up decision making.

2.6 Status-at-a-glance display methodology

Displays that allow users to step back from the details of a monitored process to assess the overall system status are the core presentation formats in the status-at-a-glance methodology. These system overview displays support coordination or navigation across the many views available within the virtual data space. Such summary displays serve as effective navigation and orientation aids and are termed longshot displays (Woods, 1984). Such displays allow the users to decide where to look next within the system. Woods and Watts (1997) indicate three functions that contribute to longshot display effectiveness:

1. status-at-a-glance display function,
2. the longshot display helps users orient their relative position in the system with respect to events that are currently occurring, events that have occurred in the past and those events that might potentially occur in the future through different types of available views while maintaining the current context, and
3. the longshot display help users navigate to all viewable displays in the structure to obtain context specific information about the system.
Woods and Watts (1997) proposed a set of guidelines for a longshot display to support status-at-a-glance:

1. Summary information must be distilled such that the situation is depicted in a concise, understandable, and thorough manner so that the users can obtain the system status,

2. Information in the summary display should integrate lower level details from different components of the system so that the user is informed about the overall system performance, that is, the information must be abstracted,

3. The longshot display should help users in finding and understanding definitive patterns of change within the system,

4. The summary information provided by the longshot display should make sense to the user in their task, and

5. Given any context, a longshot display should help the user in quickly determining potentially interesting conditions for the system performance.

Potter et al. (1992) argued that a status-at-a-glance display such as the one developed for a thermal control fault management system (Shafto and Remington, 1990) failed to communicate the dynamic aspects of system behavior, highlight events, and indicate anomalies. In their study, the at-a-glance display was required to provide a quick overview of how well the system was performing. However, the projected objective was not met. The approach turned out to be a display of raw values of the monitored process. The display did not indicate relationships between the various data elements. Potter et al. (1992) developed a
function-based display that would help the human operators understand the behavior of the monitored processes. Function-based displays are user interfaces that present goal-relevant relationships between data values to provide information about system status and function rather than simply indicating current measured data values. In the case of fault management for a thermal control system, relationships were derived using an artificial intelligence based system.

A disadvantage with using the function-based displays is that the operators need expertise in the domain of operation. Novice operators might not understand the goal-relevant relationships between system components without adequate training. Another disadvantage is that the function-based displays (Potter et al., 1992) do not display the system’s raw data values. If the raw data values are not displayed, the operators need to understand how the intelligent system works to determine the relationships. Otherwise, they will be uncertain about their decisions.

In a rapid decision making scenario, employing a status-at-a-glance display, the decision maker employs mental simulations of the scenario. These mental simulations allow the decision maker to select a course of action. The next section describes the concept of mental simulations (Klein and Crandall, 1995).

2.7 Mental Simulations

Klein (1993) presents a decision making model based on recognition that conjectures how people make use of their experience to make rapid decisions for solving a problem. The model combines two processes: situation assessment and mental simulation. People use
situation assessment to generate plausible courses of action and then use mental simulation to evaluate each course of action.

Three different recognition-primed decision making (RPD) models were devised. The simplest case of the RPD model is one in which the situation is recognized and the obvious reaction is implemented. Recognition of a situation has four important aspects: plausible goals that can be accomplished in a situation, critical cues that are important within the context of the situation, forming expectancies that help as a checklist on the accuracy of the situation assessment, and identifying the course of action. A more complex model of RPD is one in which the decision maker performs some evaluation of the reaction to uncover problems before carrying out the reaction. These evaluations are mental simulations to determine if the course of actions will work. Klein and Crandall (1995) defined mental simulation as the process of consciously enacting a sequence of events. The most complex case of RPD is the one in which the mental simulation reveals some errors in the reaction requiring some modification, or the option is rejected in favor of the next most typical reaction.

Mental simulations serve four primary functions: generate a course of action, evaluate the effect of a particular action on the problem, explain why a particular event has happened, and to plan a complete system and predict the set of events that will happen in the future.

Klein and Crandall (1995) discuss weaknesses and potential biases in mental simulation:

- De minimus and De maximus explanations

  In a De minimus condition, any irregularities in the system situation are explained away. Sometime, people might not be interested in pursuing certain
factors or cues in a model because they feel that the factors or cues do not have much impact on the situation. However, operators must be careful in determining the exact factor in the model to eliminate from supervision. An experienced operator, who fails to notice small changes in the scenario, might continue with implementation of a solution to a problem that no longer exists. The operator might be eliminating a factor that in their past experiences had little effect on the situation. However, in the current situation that particular factor may actually impact the system thus changing the status of the system and the operator would not have noticed it.

In a De maximum condition, the operator constantly performs what-if analyses on the system to assess any system situation. Klein and Crandall (1995) state that in some cases such repeated analyses of the system must be avoided because certain conditions in the system might have significantly changed or certain system constraints might have been violated and any number of system analyses will not provide a feasible solution.

- Commitment or overconfidence of the individuals

  People who often use mental simulations successfully become very convinced and confident of their ability to generate effective courses of action. These people can begin to neglect or override the evaluation of the generated action sequence. They become over confident that their generated action sequence will work. Klein and Crandall (1995) point out that neglecting the evaluation of a course of action has led to poor decision outcomes.

- Inability for people to de-center
De-centering is the ability to visualize a situation from different aspects or from another operator’s point of view. De-centering helps the operator ensure that no critical factors have been overlooked in determining and evaluating a satisfactory course of action. Although no experiments have been conducted to determine this effect, Klein and Crandall (1995) feel that people may be unable to mentally simulate an event from different perspectives.

Sometimes, people restrict the scope of their mental simulation by considering only a limited number of causal factors. They seem to have difficulty simulating multiple causes or interactions among the several factors. In complex environments, mentally simulating an oversimplification of the problem may lead the decision maker astray. Some of the factors or aspects of the person, or the scenario settings, that can affect the quality of mental simulations are explained below.

- Person / Situation factors:
  - Experience level
    Inexperienced personnel may include too few or too many factors in the simulation making it very confusing. They may construct incomplete or inaccurate scenarios. The initial values of the simulation itself might also be incorrect. Klein and Crandall (1995) believe that being able to judge the cognitive complexity that one can handle without becoming confused is very important in mental simulations.
  - Cognitive style
Based on the literature pertaining to mental imagery, there are differences in the ability of individuals to envision objects and modify some aspects of them (Seikh, 1983). Although there is no similar research applicable to mental simulations (Klein and Crandall, 1995), it is believed that the individual’s abilities and the demand of the tasks would interact to produce mental simulations that are effective.

- **Time constraints**
  
  Klein and Crandall (1995) found that time pressure did not seem to affect decision making by interfering with the use of mental simulations. They found that under high time pressure the mental simulations were less likely to have a positive impact on the decisions made. They believed that under time pressure people tended to skip the inspection / evaluation phase of the mental simulation process.

### 2.8 Trust

Researchers have defined trust in several different ways (Gambetta, 1988; Luhmann, 1988; Rousseau, 1998). It has been agreed that trust builds slowly (Kelley, 1979; Rempel et al., 1985). Rempel et al. (1985) mentioned that it is not only difficult to establish trust but, it is much more difficult to re-establish trust. Mayer et al. (1995) stated that the formation of trust depended on repeated positive interaction between the involved parties. They indicated that the most important element of trust is vulnerability and that trust is not predictable.

There are many decades of research on trust, especially from the field of psychology. A prominent focus in most of these studies has been towards studying interpersonal or dyadic
trust, with specific focus to romantic relationships (Larzelere and Huston, 1980). Methods for studying trust have also been included in exploring trust in automation (Muir, 1987; Jian, Bisantz, and Dury, 2000; Lee & See, 2004). Studies related to trust in virtual teams have come from a variety of disciplines such as business literature, computer-supported collaborative work, communications, sociology, and psychology (Wainfan & Davis, 2000).

Interpersonal trust measurements rely mostly on survey data. Rotter (1967) introduced a scale for the measurement of interpersonal trust. Rotter (1967) defined trust as “expectancy held by an individual or group that the word, promise, verbal or written statement of another individual or group can be relied on.” From this definition, Rotter (1967) constructed and validated a scale using data from 547 college students.

Rotter’s scale was later extended by Larzelere and Huston (1980) in an effort to understand the relationship between elements of trust and the related aspects of human relationships. Larzelere and Huston’s Dyadic Trust Scale is widely cited and used as a measure for interpersonal trust. Some of the questions from the survey designed by Larzelere and Huston (1980) are:

1. Members of this team are primarily interested in their own welfare
2. There are times when members of this team cannot be trusted
3. Members of this team are perfectly honest and truthful with me
4. I feel that I can trust the members of this team completely
5. The members of this team are truly sincere in their promises
6. I feel that members of this team do not show me enough consideration
7. Members of this team treat me fairly and justly
8. I feel that members of this team can be counted on to help me
The trust in automation literature incorporates performance measures, process measures, and survey data. Some well-known work in this field were by Muir (1987) and Lee and Moray (1994).

Muir (1987) attempted to find commonality between the different trust definitions by trying to understand the underlying recurring themes. The three important themes that Muir (1987) investigated were: a) the expectation of, or confidence in another that is oriented towards the future, b) that trust always has a referent, such as when trust is particular to something or someone, and c) trust could be related to the characteristics of the referent, such as honesty, reliability, and motivations.

Muir developed a model of trust between human and machine by combining Barber’s (1983) taxonomy of the component expectations of trust and Rempel, Holmes and Zanna’s (1985) taxonomy of the dynamics of trust. This model illustrates how trust evolves over time and identifies the expectations involved during that evolution.

Muir (1989) designed a two-part trust survey for the study of supervisory control in a simulated milk pasteurization plant. The first section addressed components of trust. The second section asked about trust directly. In the study, both error rates for the automation and display properties were varied across conditions. It was found that automation use increased with trust.

Lee & Moray (1994) examined issues of trust and self-confidence. Lee and See (2004) developed a conceptual model of the dynamic process that governs trust. These studies included scenarios in which the participant had to choose whether to rely on automation or use their own judgment. The trust surveys used in these studies were specific to the individual scenarios and were used to obtain self-report measures of trust in the
automation. These studies have led to important findings on the reliance of humans on technology.

Jian, Bisantz, and Drury (2000) designed a trust scale for automated systems. Although this scale has been used primarily for studies of trust in automation, cluster analysis indicated that general trust, human-human trust, and human-machine trust tend to be similar suggesting that the scale might generalize beyond trust in automation studies.

Bisantz and Seong (2001) provided perspectives from both social science and engineering research that agreed trust is a “multidimensional, dynamic concept.” Bisantz and Seong summarized research findings relevant to trust and automation and used the findings to discuss issues of human trust in automation. Consistent findings involved the correlation between trust and both current and previous performance of the system, the presence of faults in the system, and the degree and consequences of system error.

Lewandowsky et al. (2000) developed a framework to try to differentiate trust between humans from trust between humans and automation. One factor for human trust is linked to performance. Lee & Moray (1994) and Lewandowsky (2000) conducted a series of experiments exploring trust and related issues in the context of a complex task. While Lee and Moray (1994) found that trust will recover to some degree when the faults subside, the renewed sense of trust still falls below its initial level.

In an effort to study trust, studies have also focused on pattern recognition tasks, such as locating a camouflaged soldier in different terrain photos (Dzindolet et al., 2003) and visual inspection of a printed circuit board for defects (Khasawneh, 2003). An automated decision aid is used in the experimental task. Experimenters manipulated the accuracy of the automation and the amount of control the participants have over the automation. Trust data
was generally using surveys administered before, during, and/or after interacting with the automation. Data was also collected with respect to the frequency with which the automation was used.

Measurement of trust is not straightforward. Strategies for measuring trust can be broadly grouped into three categories: survey data, performance data, and comparisons (Hill et al., 2006). Variations within each category exist such as assessing trust directly, assessing trust via performance predictions, assessing trust in relation to specific tasks, and assessing components of trust.

Survey data was used in most studies of trust in automation. Analysis of surveys reveals interesting variations. Bisantz and Seong (2001) included questions referring to the system’s deceptiveness, intent, and integrity, qualities more often associated with humans than machines in addition to standard questions regarding confidence in the reliability and dependability of the automated systems. Participants were asked questions about the trustworthiness of the technology and related issues such as dependability and reliability in an absolute sense, without comparison to any other human or technology agent. Carafelli (1998) used questions assessing trust directly without addressing issues such as perceived deceptiveness. In addition to the absolute trust questions, Carafelli (1998) includes paired comparisons.

Dzindolet et al. (2003) conducted few studies using questions focusing on the performance of the automated system as trust as indicator. In one study, participants were asked questions comparing their own performance to that of the automated system. These questions were asked after practice trials, but before they began the experimental session, indicating that participants were asked to make judgments with very little knowledge of their
own skill or the skill of the automated contrast detector. In a second study, Dzindolet et al. (2003) administered the survey after participants had completed the experimental session. In this case, participants were told that they would be given a monetary reward for every correct decision they made in a randomly-selected sample of 10 trials. Participants were also informed that they could choose to have performance assessed based on their own performance or the performance of the contrast detector automated aid. Providing choices served as a strong indicator of comparative trust.

Lee and Moray (1994) took another approach, asking participants to rate their confidence in automated systems with respect to specific tasks.

While Dzindolet et al. (2003) used performance estimates as an indicator of trust, Lee and Moray (1994) asked directly about trust in an automated device (or specific function of the device) and the participant’s level of trust in him/herself to accomplish a task. In both cases, these comparison ratings were used to make observations about the relationship between one’s confidence in one’s ability to accomplish a task and trust in an automated device.

Trust in virtual teams has been studied across different domains such as business literature, computer-supported collaborative work, communications, sociology, and psychology. Most of the research involving virtual teams has been naturalistic rather than laboratory-based, and documents challenges virtual teams face.

One particularly study investigating virtual teams was conducted by Jarvenpaa and Leidner (1999). 350 master’s students from 28 universities participated in a global virtual collaboration. Participants were assigned to a team of 4 to 6 people. Team members were not co-located. Given a six month period, each team was required to develop a website providing
a new service. Email transcripts, the website, report, and survey data were analyzed. A survey adapted from Mayer, Davis, & Schoorman (1995) was used. It was found that social exchanges and communication conveying enthusiasm during the early phases of the project facilitated the development of trust. Also, specific member actions such as coping with technical and task uncertainty, and individual initiative were seen in teams with high trust initially. As the project evolved, high trust teams had predictable communications, timely responses, and were able to transition from a procedural to a task focus.

Militello et al. (2007) developed a foundational set of methods that could be adapted to answer research questions related to trust in virtual teams. Militello et al. (2007) adopted three strategies for measuring trust:

1. Performance measure: Develop a scenario in which the participant has to choose between trusting team members or anonymous “intel data.”

2. Self-report measure: Survey data has been the most direct way to examine trust. Some of the surveys are:


   b. Interpersonal Trust (Larzelere & Huston, 1980)

   c. Trust in Automation (Jian, Bisantz, & Drury, 2000)

   d. Perceived Team Cohesion (Bollen & Hoyle, 1990)

3. Process measure: Logs of the chat communication between team members can be examined for various types trust building activities such as sharing of biographical information, seeking and providing confirmation, and sharing status. From the chat logs, indicators of distrust such as conflict among team members may also be visible.
2.9 Interface design in time-critical applications

There are numerous uncertainties and disturbances in dynamic complex environments. In such environments, a key requirement to make decisions is information. When time is limited, required information must be quickly processed by the decision makers so decisions can be made quickly. Accuracy in decision making has to be maintained. Some examples of time-critical scenarios are emergency rescue operations, search and destroy missions, suppression of enemy air defenses (SEAD) in a command and control domain, hospital health care, evacuation in the case of natural disasters such as fire, tornadoes, earthquakes, or flooding, highway re-construction projects, and air traffic flow management in busy commercial airports.

Adelman et al. (2004) designed a cueing technique based on changing icon representations to test the effectiveness of distributed team decision making under time pressures. The scenario was a simulated air defense implemented using the Argus synthetic environment (Schoelles and Gray, 2001) in which the participants had to perform an Identification of Friend or Foe (IFF) task on the targets that appear on the radar screen and also exchange available information such as the airspeed, altitude, course of direction, radar and range to determine the threat level of the targets. There was one real human subject who coordinated with simulated teammates. The radar screen was split into concentric segments and the target icon changed when particular information about the target was obtained. The target icon also indicated whether subjects needed to send target information, receive target information or perform both functions. Target color and shape changed during the scenario to indicate the target’s status and the time left to make a decision about the target. The researchers concluded that regardless of icon representations, task characteristics such as
time pressure and information abundance significantly affected the information exchange between the team members, proportion of decisions made, and the decision accuracy. They also found that under time pressure, subjects did not wait to obtain all information before making a decision about a target. The subjects actually used a different decision strategy than the strategy they were trained and expected to use. Further research was suggested to determine better modes of interface development so that the task requirements do not affect the operator decision strategies (Adelman et al., 2004). They suggested the interface must also have features that support users with low working memory capacity to improve their decision accuracy.

Rauschert et al. (2002) designed and developed a Dialogue-Assisted Visual Environment for Geoinformation (DAVE_G) tool, a Geographical Information System (GIS) for effective collaborative decision making during emergency management operations that provides geospatial data directly to the decision makers. The required information was visualized on a large screen display and multi-user interactions were supported through voice and gesture recognition. The geospatial data was stored and retrieved from a knowledge-based dialogue management system. The tool uses different interaction modalities (spoken words and free hand gestures), domain knowledge, and task context for dialogue management and supporting collaborative group work with GIS. However, what happens when many people are simultaneously using a single interface screen, and each individual requests a different information set? The authors do not discuss the effectiveness with which the system status updates are provided to the users; there is only one large screen. There is no interface component that gives a concise report on the system performance. The users must
look all over the screen and understand whether their actions have improved or deteriorated the system performance.

Lehner et al. (1997) designed a display interface for a command and control scenario to determine the impact of time critical situations on the decision making effectiveness of teams of operators, specifically the effect of cognitive biases on the decision strategies. The common display interface consisted of: a) threat information window that displayed information related to the threat, b) resource for threats assignment window, c) communication window for communication between team members, d) radar display window that was divided into four regions for all team members with no information about one distinct region, e) aircraft information windows, and a f) message transfer window. Despite common interfaces, each team member controlled only one part of the radar display. The teams were trained to use a set of decision strategies to complete their tasks. However, as the time stress increased during the experiment, the subjects used a different decision strategy than the strategy they were trained to use.

Mavoian (2002) designed a decision support tool to provide airline users with real-time visibility on the Air Traffic Flow Management (ATFM) situation to improve the nature of collaborative activities between the airline operators and the Central Flow Management Unit (CFMU) involved in ATFM. The research sought to re-route vehicles to avoid congested zones and allow the aircraft to complete their flight path without any delay or with reduced delay. The ATFM efficiency was improved by coordinating route planning activities handled by airline operators, and flow management monitored by the CFMU. The ATFM interface was designed to integrate information from necessary airline units. ATFM visualizations were provided for real-time visualization of constraints on air traffic volume.
during specific time periods, display of constraints on airlines route options, and visualization of congestion status on airline route options. Global views along with “what-if” re-rerouting options were provided. However, there were no statistical visualizations such as graphical charts to provide data such as the percentage level of congestion status in different zones. Such a tool might assist the users in analyzing and interpreting and implementing feasible aircraft routes without the need for re-routing across at least a set of airports until some particular time in the future. In planning a route, proper allocation of resources is important. All required information regarding resource availability at the selected airports for a route should also have been displayed on the interface.

Cummings (2003) designed a human operator interface that could be used in a combat scenario requiring constant monitoring and retargeting (re-planning missions) of a Tomahawk land attack missile, called a Tactical tomahawk, which can be redirected in-flight. The human operator must re-target such missiles when there are ‘emergent or pop-up targets’. The designed interface primarily consisted of a map display, a tabular presentation of missiles and targets that are in strike range of the missiles, and a chat window for communication. The map display is used for monitoring all the missiles and targets superimposed on the map of the specific terrain. The interface has a time bar that provides the user with all necessary time-related information of each missile. The tabular representation is a decision matrix used by the operator to obtain the current status of all missiles capable of retargeting and all missile-target pairs. The experimental study found that the chat window diverted operator attention away from the primary task of monitoring and retargeting missiles. It was also found that the subjects were unable to use the trained decision strategy called ‘parallel decision processing’. The idea behind this decision strategy
was that in conditions when there were two emerged targets (pop-up targets), the operators should simultaneously make decisions on both of the emerged targets while taking into consideration the available resources (missiles) and try to attain an optimal solution.

Tso et al. (2003) designed a human factors experimentation testbed for command and control of unmanned aerial vehicles (UAVs). The testbed was specifically developed to study operator interaction with systems having varied automation levels and decision aid fidelity. The interface consists of a Tactical Situation Display (TSD) with waypoints used by the UAVs, targets, and threats overlaid on it. The TSD provides a plan view of the environment and is used by the operators to monitor the UAV missions. The system also provides a 3D model of the UAVs in the environment either as the pilot’s view from the UAV or a global view of the environment. During a mission, UAVs capture images over the target locations. These images are stored in an image queue database. The Image Queue provides an interface displaying the image with the target object information detected by the automatic target recognizer (ATR). The images are displayed in the order in which they are stored in the database. The images remain in the database for a period of time after which they are automatically accepted or rejected without the user’s knowledge or intention. To improve this testbed, the interface should alert the user that the image will be deleted automatically without the user intervention. Also, under conditions of the emergence of pop-up targets, the system has an auto-replanner that changes the route of a particular UAV. The user does not influence the UAV route planning. Provisions should be given by the interface so that the user can be involved in the replanning of UAV route as in Ganapathy (2006).

John et al. (2000) designed a display to aid a supervisor in monitoring a developing situation in the command and control environment. They referred to the display as a Task
Manager Display (TMD) because it helped the supervisor in organizing and evaluating alert messages as they applied to ongoing tasks executing within the system or from the people in the tasks. The on-going tasks were graphed on a Gantt chart, with color codes to indicate differences in task priority.

Griffith and Smith (1997) developed a system for mission monitoring, re-planning and re-tasking of missions particularly in critical situations with unexpected events. Information is displayed as maps, tables, and timing charts. The system has separate ‘status reporting windows’ for each entity in the scenario displaying only the raw data values for each entity. In certain cases however, the system provides two tabular windows displaying duplicate information. Such duplication of information should be avoided in time-critical situations. If possible, the status windows of entities with similar properties should be integrated to avoid information duplication and free up space on the interface to display other important features and information.

Shafto and Remington (1990) designed a status-at-a-glance display for monitoring the behavior of a thermal control system (TCS), part of NASA’s Space Station Freedom. The researchers developed a display to provide a quick overview of how well the system was performing its functions. However, the display only consisted of spatially arranged sensor data about the state of the monitored process. It failed to project the dynamic aspects of the system behavior, highlight critical events or indicate anomalies. Potter et al. (1992) continued work on the TCS to design a function-based display that would support the status-at-a-glance display by Shafto and Remington (1990). The function-based display obtained additional higher level system details regarding the performance of the TCS through artificial intelligence based systems which worked as fault management systems. However, such
visualizations can only be interpreted and used if the operator of the TCS is an experienced individual.

Chuang and Chou (2005) designed a human-system interface for a nuclear power project for plant monitoring and control. Interviews and experimental study determined that for such an interface, sufficient training must be given to the plant operators so that unexpected situations could be properly handled. Training must be provided so that the operators can memorize the display locations to reduce delays in obtaining the required information for a task. Reducing delays to obtain information reduces operator cognitive load.

Liberman et al. (1993) designed a status-at-a-glance user interface for a power distribution system. To address the problem of information overload, an interface was designed that integrated an expert system’s (fault detection) diagnoses with the actual process data and hence keep the operator’s attention on important aspects of the power distribution system. The user interface consisted of a schematic diagram of all system components. One portion of the screen consisted of control buttons that operators can use to control the amount of information shown on the screen. This feature allows removal of irrelevant information and reduces clutter on the screen. Another part of the screen was used to obtain text messages regarding unexpected events or failures in the system. Selection of the text messages provided detailed description of a problem. Visual cues were used to notify the operator regarding the related devices for a problem. Whenever a new message appeared in the text area, an alert button was activated to alert the operator. In this interface design, the researchers used color codes to maintain the attention of the operator on specific components and awareness of which components were experiencing problems. Under conditions where
the operator can control the quantity of information displayed on the screen, there should be some part on the interface that provides information on the performance of the overall system and its components, which also gets continuously updated. Similar to previous examples in time-critical situations, there is actually no part of the interface that gives complete at-a-glance information regarding the entire system. The utilization of too many visual cues, especially in the form of color codes and alerts, can affect the user performance. The users of the system may require more training to become accustomed with the system interface features.

All the above-mentioned applications indicate that researchers are trying to present all available information and reduce the cognitive load on the users of the system. However with new technologies, the operator’s role has begun evolving into that of high-level supervisory control (Wickens, 1984). As the operator’s role changes from manual control to higher levels of control, there is significant change in the information that has to be handled effectively by the operator. Other than obtaining and understanding the information, the operator would have to make valuable critical decisions in real-time with the available information sets (Rouse et al., 1987). Such circumstances can cause an increased cognitive load on the operator. The next section describes studies conducted in dual-task environments particularly with respect to interruption management and interface design to improve human performance.
2.10 Studies conducted in dual-task environments

A good deal of research over the past decade has investigated techniques to improve human performance in dual-task conditions. Most of the work has been related to how users overcome interruptions and complete the goals defined for both task scenarios. In this section, research studies in dual-task environment are described.

In dual-task environments, the users perform the tasks either simultaneously (parallel or concurrent processing of tasks) or serially (one task followed by the next task). For example, consider an individual using a 17-inch computer monitor and doing two tasks – typing a document in Microsoft Word and voice chatting. In parallel task processing, the user may split the screen to accommodate the word document window and the chat interface window side-by-side. The person could be typing a document while at the same time be involved in voice chat through a webcam. Their gaze would move between windows. In serial processing of tasks, a single screen is used. The person alternates between typing the document and using the chat interface.

Kreifeldt and McCarthy (1981) studied the effect of interruption in a dual-task scenario comparing the interface designs of Reverse Polish Notation (RPN) and Algebraic Notation (AN) calculators. During interruption, the participants’ task was to write multiplication tables. Performance comparison showed that the primary task was completed faster with RPN calculators. However, it was found that on both calculator types, after primary task resumption, primary task performance speed reduced. It was not clear to the experimenters whether, at the onset of interruption, participants began the secondary task immediately. They believed that similarity between the tasks could have been a factor in interruption disruptiveness.
In Field’s (1987) study, users queried a menu-driven database for completing tasks in the primary task. The database user interface navigability was varied between a Selective Retreat (SR) condition which allowed users to retreat to any previously selected screen and a Restricted Retreat (RR) condition which allowed retreat to either the previously viewed screen or the main menu. During a given trial, participants performed simple and complex tasks, which were interrupted to complete a numeric sequence or a find a title of a book. Results indicated that even though interruptions affected performance, tasks were completed more effectively in the SR condition. Interruptions length did not have an effect on user performance. Field (1987) believed that SR helped users in building cues for short-term memory thus enabling them to access the database more efficiently upon task resumption. Surprisingly, there was no significant difference in resumption lag between simple and complex tasks indicating that task complexity might not have been varied significantly.

Gillie and Broadbent (1989) conducted experiments to investigate the effect of interruption characteristics such as duration, task similarity and task processing complexity. The primary task required the subjects play a computer-based adventure game in which they had to collect a specific number of items in the simple and complex task conditions. Interruptions occurred and the duration varied from thirty seconds up to 2.75 minutes. For both interruption durations, when the interrupting task was a simple mental arithmetic task (dissimilar from primary task), subjects were allowed to rehearse their position on the primary task before performing the interrupting task. Results showed that there was no disruptive effect of interruptions. Experimenters concluded that the subject memory load at the time of interruption does not guarantee interruption disruptiveness. They also found that after interruption, upon task resumption subjects always performed slower on the primary
task. This situation was explained as subjects having to retrieve past events from memory. In two additional experiments, the interrupting task was either a complex arithmetic task with numbers being coded as characters or a task in which subjects were required to speak aloud words displayed at regular intervals and finally write down all words displayed. These experiments showed that interruption disruptiveness was related to its task complexity, shorter time duration, and mandating users to begin the interrupting task immediately without rehearsing their position in the primary task.

Storch (1992) examined the disruptive nature of interruptions, whether the style of user interface or the form of interruption were the underlying factors in a data entry task on a personal database. One set of subjects were given a graphical user interface with a mouse and screen buttons while another group was provided a character-based interface with tab and function keys. All subjects were exposed to three interruption forms: telephone call, on-screen message, and a walk-in visitor. Results indicated that the on-screen message interruption was the most disruptive while the telephone interruption was least disruptive. The disruptive effect of on-screen messages was due to the pop-up messages not allowing the user to complete the ongoing entry before attending to the interrupting task. Comparing the style of user interface, there was no significant difference in task performance. Storch (1992) suggested that in the design of multi-window user interfaces, it is important to avoid disruption due to an on-screen window pop up and that different variations of interface style and input devices must be examined.

Kaber and Riley (1999) conducted a study to explore the issue of human-directed or automated-directed invocation of adaptive automation (AA). An experiment was conducted in which users were required to perform dual-tasks, a simulated radar monitoring and target
elimination primary task and a gauge-monitoring secondary task. In this experiment, based on the user’s secondary task workload measurement, a built-in computer assistant either suggested or mandated the user to change the primary task control mode from manual control to partial automation control. The two computer-based tasks were presented to the user through different monitors. In the primary task, users were presented with targets of different sizes and colors that traveled at different speeds towards the center of the display. The targets had to be destroyed before they collided with each other or before they reached the display center. Simultaneously, the users had to perform a gauge-monitoring task that required them to monitor and correctly detect deviations in pointer movement on a fixed scale from a given acceptable region. When the number of incorrect detections exceeded a pre-defined value, mode control changes were either suggested or mandated by the system.

Cutrell et al. (2000) described the effect of instant message interruptions on performance during different phases of the primary task. The primary task consisted of a web search task and an analysis of the graphic design layout of the selected website. The search phase of the task was broken into a planning phase, searching phase, and finally the execution phase, during which the users selected the website best matching the requirements. After selecting the website, the website design layout was analyzed and the design category was rated by the user. During the search phase, instant message notifications appeared on the screen. The instant messages were either relevant or irrelevant to the search task that was being performed at that time. Experimental analysis of results revealed that the time taken to switch to the instant message was slowest during the execution phase. Also, the time to resume the search phase was longer when the messages were irrelevant. Experimenters noted
that users delayed switching to the interruption task until they had completed their ongoing website search phase.

Czerwinski et al. (2000) conducted experiments to explore the effect of notification interruptions during the execution phase. An experiment was designed in which participants were asked to search for a book title from a huge list of titles displayed on a Microsoft Excel worksheet that participants navigated either using the up-down arrow keys to scroll with a marker outlining the selected box on the worksheet or using the page up-page down arrow keys without any marker outline. The search target was displayed at the top of the worksheet, which was either the verbatim title of the book or a one-line summary of the book. Interruptions required the participant to perform simple arithmetic operations. Results showed that irrespective of search condition, notifications were disruptive. There was a larger increase in resumption time due to interruptions in the search by title condition compared to the search by summary condition. The navigation style did not have an effect on resumption time.

Maglio and Campbell (2000) conducted three experiments to explore the distraction issues with displaying peripheral information. The dual-task condition created here was a text-editing task (primary task) and a headline-reading task (secondary or peripheral task). All three experiments had two phases. In phase I, only the text-editing task was given to the user. In phase II, the user was involved in the dual-task condition. Performance of the user on the text-editing task was the baseline. The experimenters examined the effects of scrolling motion of three single-line text displays (that the authors referred to as tickers) on editing and remembrance performance of displayed information in dual-task conditions. Remembrance performance was measure based on the number of single-line text displays (news headlines)
recognized by the users in a post-experimental study. They tested tickers of three varieties – continuous scrolling text, discrete scrolling text, and serial presentation on the basis of speed of text and then on the direction of text. They also tested whether auditory or visual cues versus scrolling would dominate human performance. Their results found that continuous scrolling motion provides more distraction and less feedback than discrete scrolling motion; display direction does not affect editing performance; visual cues (flash ing background display on headline reading window) or auditory cues (simple beeps) when new headlines appeared lead to worse performance than discrete scrolling text. Thus, having at least some motion in the secondary task window is an effective method to help users schedule attention to that peripheral display.

McCrickard et al. (2001) investigated whether animation could be effective in maintaining information awareness in the peripheral display. Two experiments were conducted. In the first experiment, the relative performance of participants was compared when using peripheral displays such as fading, tickering, and blasting displays as well as when using no peripheral display. The second experiment investigated whether display size and animation speed effected performance. In both the experiments the primary task was a browsing task and the secondary task included a set of monitoring activities with a series of awareness questions. The primary and the secondary task displays were shown together and the tasks were conducted concurrently. In the browsing task, the participants navigated through a hypertext space to find particular information, enter the information into a textbox that was connected to the browsing window, and click on a button to continue browsing. In the monitoring task, the participants monitored the peripheral display for information that must match a required criteria provided to the participant on a display window. After each
experimental trial, participants were given awareness questions and were asked to recall information shown in the peripheral display. Results from the first experiment showed that the time to complete monitoring tasks was significantly faster with a blast display than a fade and ticker displays. McCrickard et al. (2001) note that the type of peripheral display depends on the goal of the monitoring task. If the goal was to identify information quickly from the peripheral display, then blast and fade displays were better display modes. If the goal was to improve memory of the displayed information, then ticker display was a better display mode. Results from the second experiment showed that both the size of the peripheral display and the speed of the displayed information affected performance. In the ticker display mode, a larger display size caused the participants to take longer time to complete the monitoring task. The researchers believed that with larger displays, a faster display speed improved memory of the displayed information. However, the display speed depended on the amount of new information displayed at-a-glance. It was also found that single-line peripheral displays were easier to comprehend at-a-glance than multi-line peripheral displays especially when fade and blast displays were used. McCrickard et al. (2003) also indicate that in the case where the primary task is a browsing task, for notification in the secondary task, the slow fade animation mode was found to provide the best support to the user.

Bailey et al. (2001) conducted an experiment to determine the effect of interruption on the user’s task performance, annoyance and anxiety. The experiment consisted of six primary task categories and two secondary task categories. The primary task categories were addition, counting, image comprehension, reading comprehension, registration, and selection while the secondary task categories were reading comprehension and stock selection. In the study, two groups participated. The first group was interrupted just after completion of the
primary task while the second group was interrupted while performing the primary task. Results showed that users performed slower on an interrupted task (primary task) than on a non-interrupted task (secondary task), the level of annoyance experienced by the user depended on the category of the primary task performed and on the time at which the secondary task was displayed, the anxiety level experienced by the users was greater when the primary task was interrupted than when it was not interrupted, and the users generally perceived that an interrupted task was more difficult to complete than a non-interrupted task.

McFarlane (2002) conducted experiments to determine if the nature of the interruption affected user performance in dual-task environments. Four types of interruption were defined for the study: a) immediate interruption condition where the users were presented with the secondary task at any instant irrespective of the state of the primary task, b) negotiated interruption condition where the users had control over handling the interruption and performing the secondary task, c) mediated interruption condition where the interruption occurred only when the workload metric measured on the users for the primary task they were performing showed a low value, and d) scheduled interruption condition where all the interruptions were held up by the system and the switch from primary to secondary task occurred on a pre-arranged regular time interval schedule. In this study, the primary task was a gaming task and the secondary task was a matching task. The gaming task required the users move a vehicle-like object and catch game characters as they jumped from a building. The matching task required the users to match objects based on their color or shape. When the users performed the matching task, the gaming task continued to occur but was blurred. Results from the study showed that the accuracy and efficiency on both the tasks were best under negotiated and mediated interruption conditions. The efficiency and
accuracy was worse under scheduled interruption condition and immediate interruption condition for the primary task and the secondary task respectively.

Tessendorf et al. (2002) conducted experiments to determine whether display design guidelines for focal images could be extended to images displayed in the secondary task. Design guideline effectiveness was measured in terms of image attributes such as position on the screen, area occupied by the image, and the color of the image. The experimental condition involved users playing a game which was displayed on the left portion of the screen and one image with the similar dimensions as the game display was shown for a few seconds on the right portion of the screen. Results from the study showed that the user ability to retrieve information from images was better when the image was displayed in the focus rather than as a secondary task. The highest percentage of correct information retrieval was observed in position-encoded image conditions. Considering color-encoded versus area-encoded images, the former seemed to be more effective at low levels of primary task degradation, while the latter was effective under higher levels of degradation. Researchers concluded that display attributes should be selected based on permissible primary task performance degradation.

Sauer et al. (2002) investigated the benefits of integrated information display. The primary task involved ship navigation in an automated environment while the secondary task involved monitoring oil temperature, resetting temperatures to a safety level during temperature drifts and logging cargo temperatures at regular intervals. For the primary task, three types of information display were designed: integrated display (ID) where radar display screen and chart display screen were superimposed on one another, functionally-separate displays (FSD) where the two display screens were shown on the same monitor and the
displays could be sequentially selected by toggling between their respective interface screens, and spatially-separate displays (SSD) where the two display screens were shown on separate monitors. Results showed that primary task performance was best under the ID condition. However, the ID condition showed conditions of increased workload and fatigue probably due to information overload. With increased complexity, both task performances decreased which might be due to information overload in the primary task leading to negligence in monitoring the secondary task.

Somervell et al. (2002) evaluated whether textual display or graphical display was better in the secondary task display for notifying information to users. The primary task was a browsing task and the secondary task required the users monitor a simulated computer load represented in a graphical or textual mode. The computer load displays were updated at a slow or a fast rate. The experiments did not provide conclusive evidence to the researchers whether one particular display mode was best. Other insights were gleaned from the study. The user awareness of the displayed information was best under the fast-graph update display mode and worst under the fast-text update display mode. The degree of distraction of the secondary task on the primary task was also measured. The primary task performance was measured based on the total time taken to correctly answer all questions related to the primary browsing task. It was found that fast-graph and fast-text update displays enabled faster completion of the primary task than the slow-graph update display. It was also found that user response rate to information changes in the secondary task was highest under the slow-text update display condition and least under the fast-graph updates display condition.

Somervell et al. (2002) conducted a study to evaluate the effect of visualization characteristics such as visual density (low and high density), image presence duration (1
second and 8 seconds), and the type of secondary task (locating a single object or a cluster of objects) on primary task performance and correctness in the secondary task. The primary task was a video game task while for the peripheral secondary task, participants answered questions related to a displayed image. Results indicated that peripheral visualization could be achieved without affecting primary task performance. Identification of a cluster of visually similar items seemed easier than single item identification. Under relaxed time constraints, all visualizations could be correctly interpreted. In dual-task situations, it was found that users could perform better with low density displays than with high density displays thus suggesting that information abundance (relevant or irrelevant) can hinder the performance.

Bartram et al. (2003) examined whether small motions of icons would be a better notifying technique (easy to detect and identify) than changing the color of the icon or the shape of the icon. In an experiment, the primary and secondary task window could be seen together. The primary task window was a very small window to the right of the secondary task window. The primary task was an editing task in a window containing a scrollable table of numbers from zero to nine. The participant had to find all zeros in the table and replace them with ones. In the secondary task (the large window), there were fifteen dispersed icons of different shapes presented to the participant. The participant had to detect a change in one of the icons due to motion change or color change or shape change. Once the change was detected, the experimental trial was over. It was found that icon changes could be detected with relative ease with the help of the motion change cue. The color change and the shape change cues were very ineffective compared to the motion change cues when the icon targets were located in the ‘FAR’ region on the large window, that is, the icon targets were located
towards the upper or lower portions of the large window and not around the center portion of
the window (‘NEAR’ region).

Altmann and Trafton (2002) proposed the concept of an interruption lag during which
users could rehearse the task resumption point. The interruption lag is the time span from
when the user is warned about the secondary task to the time when the secondary task
actually begins. The instant at which the user is warned about the secondary task, the primary
task they are performing is completely paused by the system and the user interface is frozen
to prevent changes to the system. Conceivably, the interruption lag allows users to create a
mental model of the primary task situation and hence a mental picture of the task goal they
are pursuing before beginning the interrupting task. This memory retention of the primary
task might help the user effectively resume the primary task after interruption.

Miller (2002) examined whether interruption lags reduces the disruptive effect of
complex tasks by users using this time to rehearse the primary task resumption point
(rehearsal strategy). A team task of monitoring and assessing the threat level of aircraft
appearing on a radar display was simulated. Aircraft on the radar display either carried all its
relevant data for the user to assess its threat level or some data about it was missing. The
missing data on an aircraft appeared as an instant message. This was the interruption task and
the user needed to remember the data that appeared in the instant message for use with a
future aircraft or currently monitored aircraft. Interruptions seemed to significantly affect
performance with respect to decision making time. Decision accuracy did not significantly
decrease with interruptions. Interruption lag and the rehearsal strategy did not benefit task
resumption. Subjective responses revealed that in most cases participants did not rehearse
their response. Results showed that participants who did not perform the rehearsal strategy

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made decisions quicker. Miller (2002) believed that participants gave more importance to remembering data displayed in the interrupting task and they lost track of their resumption point leading to the performance degradation.

Trafton et al. (2003) also examined the interruption lag time period to determine if this lag period would help the users resume their interrupted task effectively. The researchers created a scenario where the primary task was a complex resource allocation task and the secondary task was a simulated tactical assessment task. The experimental session consisted of twenty minutes on the primary task during which there were ten interruptions. Each interruption lasted for thirty seconds during which the secondary task was performed. The interruptions could be an immediate switch to the secondary task or a switch after the interruption lag of eight seconds. The results of the study showed that interruptions were disruptive to performance. The participants resumed the primary task more effectively when they were provided the interruption lag than when they were directly taken to the secondary task without providing time to construct a mental model of the primary task. Altmann and Trafton (2004) continued this work and found that due to interruptions, the resumption lag (time taken to restart a task after interruption) was significantly higher than time taken between uninterrupted actions.

Speier et al. (1999) looked into the effects of interruption characteristics such as frequency of occurrence and similarity of interruption task on users’ accuracy and time in decision making in an environment of varying task complexity. The simple task involved scheduling machines in a job-shop while complex tasks were either a facility location task or a aggregate planning task. The interruption tasks were either similar to the primary task or they were dissimilar. In one experiment, the effect of interruption while performing simple
and complex tasks was investigated. In another experiment, interruption frequency and interruption task similarity were varied while the primary task was a complex task only. Results showed that interruptions facilitate performance in simple tasks while affecting performance in complex tasks. Increasing interruption frequency affected performance on primary task causing decrease in decision accuracy and increase in decision time. Similarity of interruption task to primary task did not have an effect on decision accuracy in the interruption tasks, but decision time was longer for dissimilar interruption task-primary task combination.

Speier et al. (2003) explored whether the information presentation format in a decision support system is critical to reduce the effect of interruptions on task performance. The information presentation formats were either tabular (spatial representation) or graphical (symbolic representation). The primary tasks were similar to Speier et al. (1999). The interruption task required participants obtain information to questions shown on the display. It was seen that in simple tasks, irrespective of the presentation format, decision accuracy was higher when users experienced interruptions than when there was no interruption. In complex task with interruptions, decision accuracy was always low. Performance degradation was less in spatial presentation than symbolic presentation. In complex-symbolic tasks without interruptions, spatial format resulted in higher decision accuracy. The graphical format assisted in completing the complex-symbolic task faster. However, decision accuracy during interruptions in complex-symbolic tasks was similar under both presentation formats. There was no change in decision time for a complex-symbolic task as a result of interruptions, whereas, in complex-spatial tasks, interruptions increased the decision time.
Cades et al. (2006) conducted an experiment to determine whether people could be trained to resume the primary task effectively after interruption. The primary and secondary task setup was identical to Trafton et al. (2003). Participants performed three sessions of the primary task with one, two, or all three sessions being interrupted. In conditions when only one or two sessions were interrupted, the trials with no interruption were completed first. Results from the study showed that, with practice, people performed the primary task better. Performing consecutive interruption-laden trials, primary task resumption lag decreased, showing that with practice, participants begin to learn to handle interruptions.

Cades et al. (2007) explored the effect of the difficulty level of three types of interrupting tasks on the ability to resume the primary task. The primary task required participants to program television show recordings on a VCR using a designed VCR programming interface. In one interruption condition (easy task), participants had to repeat aloud numbers read by the computer. The other interruption conditions were variations of the n-back working memory task (Dobbs and Rule, 1989): 1-back and 3-back tasks. Participants had to listen to numbers read by the computer and compare the recently read number with the one read before it (1-back task) or the one read three numbers earlier (3-back task) and react if the recent number was higher or lower in value by clicking on “Higher” or “Lower” buttons shown on the interface. During interruption, the VCR interface was replaced with the interrupting task interface for thirty seconds. Results showed that with practice, resumption was faster after performing the 3-back task than the 1-back task indicating that interruption difficulty did not significantly affect task resumption. The study also showed that with increased practice, resumption time decreased linearly validating results from Cades et al. (2006).
Ratwani et al. (2006) conducted an experiment to determine whether interruptions improve performance in a simple task, such as found in Speier et al. (1999). In the primary task, participants scrolled sequentially through a list of three-digit numbers displayed in a single column on a Microsoft Excel worksheet and entering all the odd numbers in that list into another column. The interruption was an instant message popping up, containing numbers that had to be added mentally and the final value entered into the message window. The interruption task window blocked viewing the primary task. Results showed that the resumption lag was much longer than a single action during the no interruption condition. Though results from Speier et al. (1999) could not be validated, it was seen that during trials with interruptions, decision accuracy in the primary task was higher and the inter-action intervals were also faster. Further analysis on eye fixation revealed that faster perceptual processing resulted in better performance.

Weisband et al. (2007) studied the effect of notification delivery method on task performance and the frequency of task switches in a three-member team primary task and individual secondary task. The primary task was the scheduling of incoming patients to an operating room in an eight-hour hospital work shift. The secondary task was reading short messages and answering related questions. The notifications contained unexpected new events that caused changes in the initial schedule which had to be taken care by the team. Such notifications were delivered either as pop-up messages (active notification) so that the team members had to attend to these messages immediately as notifications displayed on an electronic message board (passive notification), which meant the team could check the message board at their convenience. Results showed that task switches were more frequent in the passive notification trials, contrary to what was expected by experimenters. As the
number of task switches increased, performance on both the tasks showed improvement. However, experimenters could not properly validate the improvement shown in secondary task performance even with very frequent task switches. In passive notification conditions, participants were not warned about the delivery of a new message, which explained the frequent task switches and hence participants had difficulty performing the tasks.

Smallman and St. John (2003) developed CHEX (Change History Explicit) for supporting users in maintaining situation awareness in a dynamic environment when monitoring a situation and also recover their situation awareness after an interruption. A CHEX table list is created by the automatic detection of changes by the system. The significant changes that occur in a situation are logged into a table that can be sorted by the user to match specific tasks. Each time a change occurred, a new row was added to the top of the table. Selection of a row of the table links to the related objects on the map display (geoplot). If several changes to an object are present on the table, selection of one row (entry) highlights all other rows (entries) of that particular object. A naval air warfare scenario was simulated and the interface with CHEX tool was compared with a baseline interface, both of which had the map display. Other factors in the experiment were the aircraft density on the map display (high density and low density) and the task performed (monitoring task or reconstruction task). During the monitoring task, participants monitor the environment for one to three minutes after which time the scenario was paused for 3 minutes and the participants recorded answers based on the perceived scenario. In the reconstruction task, participants performed mental arithmetic task for a minute while the scenario was playing out of sight of the user. Then, participants returned to perform the change identification task. The identification time and the errors were analyzed. The CHEX tool significantly improved
human performance on humans maintaining and recovering SA, though recovering SA took relatively longer time.

St. John, Smallman, and Manes (2005) continued experiments with the CHEX tool. They compared the interface with CHEX tool condition with four other conditions – baseline, basic replay, explicit replay, and explicit markers. The baseline condition consisted of the map display with a data display on the lower right corner of the screen. The basic replay condition included a replay button allowing rapid replay since the last interruption. In explicit replay condition, for any change, a red triangle marker was added to the aircraft symbol and a ‘pop’ sound was given. In the replay mode, the markers and sound appeared at the time of change in the scenario. The markers were removed at the end of replay. In the explicit markers condition, there was no replay mode. The red triangle marker and the ‘pop’ sound condition still existed. The markers were removed as the changes were reported by the user. In the CHEX interface, the new addition was the audio signal (pop sound) given for every new entry in the table. During the experimental trials, there were 30 second and 120 second interruptions without warnings. During interruptions, the screen was blanked and the user was asked to rate the mental workload using the NASA TLX. Before the end of the interruption (10 seconds prior), a warning signal was given so that participants could be ready to resume the primary task. During all trials, data with respect to the response time to report changes, the number of misses (changes that were not reported), and the number of errors (reporting a wrong aircraft attribute) were collected. Results showed that the CHEX tool led to faster response time and produced fewer errors. The explicit markers produced fewer misses than the CHEX tool indicating that the red triangle markers help in detection. The basic replay tool caused the worst human performance, even worse than the baseline
interface condition. Even with the CHEX tool, there was a resumption lag of 10 seconds to report the changes that had occurred during interruption.

There are some concerns about the CHEX tool. It is not clear whether the CHEX tool can assist an operator in a semiautomatic environment. It appears, other than monitoring the system, the operator can only control the behavior of the dynamic entities in the scenario. The CHEX tool concept could be useful in monitoring and control environment when the operator is resuming the primary task after a period of interruption. During interruption, the system is fully automated and hence the CHEX can list all individual changes that occurred in the system. However, in the experiments conducted with CHEX, the operators were not put into any kind of high stress situations during the interruption. Will the operators be able to resume their primary task as effectively as in the earlier experiments with CHEX, if they were to monitor and control a completely different dynamic environment in the secondary task scenario and the interruption prolonging over more than two minutes time period (Smallman and St. John, 2005)? The CHEX tool also does not give information to the operator about the overall state or performance of the system during the interruption.

Scott et al. (2006) also examined the usefulness of interruption recovery tools. The primary task involved dynamic monitoring and control of Unmanned Aerial Vehicles (UAVs) while the secondary task was to find locations on a map in another room. The interruption recovery tools consisted of video replay tool that replayed past events at an accelerated speed of ten times the normal speed. The tool was equipped with an event timeline. Selection of a particular time from the timeline progress bar would display the scenario status at that time in history. They modeled two variations of the recovery tool – bookmarked assistance and animated assistance. In bookmarked assistance, an accelerated
video replay of events elapsed during interruption was viewable. In animated assistance, the event timeline contained pointers on the timeline bar called event bookmarks. When a bookmark was selected, the scenario at that instant was displayed on the video replay window. Results from experimental trials indicated that the video replay tool did not seem to be very effective. Though the bookmarked assistance type helped in faster task resumption, the event timeline seemed to be cluttered because of the bookmarks causing selection of the right bookmark to be a hassle and hence increasing the resumption time. It was also found that participants had difficulty in relating current system state on the map display to past events indicated on the event timeline and displayed on the video replay tool.

As this section demonstrates, there has been a good deal of work on dual-task scenarios but the work is not without concerns. The next section describes the interface design methodologies developed for complex systems to alleviate problems due to information presentation and enhance problem solving.

2.11 Methodologies for User Interface Design

Vincente and Rasmussen (1992) classified the events within complex systems into:

1. familiar events as those that are experienced by operators frequently,

2. unfamiliar but anticipated events as those events which operators do not often experience but are known to occur by both the operators and the system designers, and

3. unfamiliar and unanticipated events as those events that rarely occur and neither the operator nor the system designer expected such an event; accurate system in-
built solutions are not available for such events and the operators must use their knowledge about the system to come up with appropriate solutions.

To handle these varying categories of events, methodologies and design principles have been developed and implemented to aid in constructing displays and operator interfaces for monitoring and control applications. Some of these modeling techniques are Operator Function Model (OFM), Direct Manipulation Interfaces (DMI), abstraction hierarchy (AH), Ecological Interface Design (EID), GOMS (Goals, Operators, Methods, and Selection Rules), and Cognitive Task Analysis (CTA). Each is briefly described next.

2.11.1 Operator Function Model (OFM)

The Operator Function Model (OFM) approach, as described by Mitchell (1987), is a heterarchic-hierarchic network of nodes. The OFM originated from Miller’s (1985) discrete control model. The OFM implicitly represents the system goals in the form of operator tasks and actions which have to be completed; these are states that need to be achieved, similar to most control systems (Mitchell, 1999). OFM is capable of representing the multiple concurrent tasks that the operator has to manage in a complex dynamic system (Chu and Mitchell, 1995). There is no explicit representation of the operator goals. Each node represents an operator activity. Nodes at the top level of the hierarchy are the major operator functions which are then broken down into a collection of sub-functions, tasks, and actions. The operator actions performed are cognitive or manual actions.

Heterarchy can be depicted by many kinds of relationships: a) an activity decomposes into a set of activities and all these sub-activities should be carried out simultaneously, b) one activity is occurring and other activities are carried out simultaneously with the first activity.
only when initiating conditions are triggered; the initiating condition for an activity need not be triggered by existing activities, c) an activity will always be occurring and the other activities will occur when specific conditions are triggered in the first activity; the first activity will continue irrespective of whether the other activities have / not terminated, d) an event which is an outcome of an activity initiates a new activity, e) an activity decomposes into a set of activities from which the operator chooses only one activity to occur, and f) an activity decomposes into a set of activities from which the operator can chose one or more activities to occur simultaneously (Mitchell, 1987).

Thurman and Mitchell (1994) used OFM to develop a methodology for the design of an interface for effective monitoring tasks and suggested a set of guidelines for incorporating interaction into such monitoring interfaces. The OFM model was used in the supervisory monitoring and control of Unmanned Combat Aerial Vehicles (UCAVs) specifically to decompose the actions that the human operator has to be perform in a search and destroy mission in a hierarchic manner (Narayanan et al., 2000) and in a routing application (Ganapathy, 2006). The OFM model has also been used in the design and development of an intelligent tutoring system for supervisory control system operators (Chu and Mitchell, 1995).

2.11.2 Direct Manipulation Interfaces

Hutchins et al. (1985) introduced the concept of Direct Manipulation Interfaces (DMI). DMI systems allow visualizing an application domain in terms commonly known to the user(s). There are two underlying concepts in the DMI approach:
1. The information processing distance between the operator’s intentions and the facilities provided by the machine to achieve them. Distance is the relationship between the task that the operator has to perform and the method by which the task can be accomplished using the operator interface. Reducing the distance brings the feeling of directness to the interface by reducing the effort required from the operator in reaching the goal. A short distance means that the operator’s intentions can be converted to meaning actions on the interface easily and the system output can be easily interpreted.

2. For effective manipulation, the system must provide representations of objects that behave as objects themselves. That is, whatever changes are made to objects as a result of a set of operations should be depicted in the representation of the object itself. The same object is used as both an input and output entity.

The term direct manipulation was first coined by Shneiderman (1982, 1983) to refer to systems that have the following properties:

1. Continuous representation of related objects for the scenario,

2. Use of labeled buttons or other physical actions instead of complex syntax, and

3. Capability for fast reversible operations so that the impact on the related objects is seen immediately (Shneiderman, 1982, pp.251)

Hutchins et al. (1985) are convinced that interfaces are one of the main reasons for introducing gaps between the user’s goals and his/her knowledge and the level of description provided by the system with which the user has to interact. These gaps in the system are referred to as the gulf of execution and gulf of evaluation. The gulf of execution is related to the commands and mechanism of the system that match the thoughts and goals of the user.
The gulf of evaluation is the distance related to the output displays of the system that can be easily interpreted and evaluated by the users. The smaller the gulfs of execution and evaluation, the better the interface, implying that directness is inversely proportional to the amount of cognitive resources or cognitive tasks required in using the system.

In DMI systems, the desired operations are performed by moving and connecting the appropriate icons on the screen. Connecting the icons is similar to writing a program with the added advantage of directly manipulating the data and the connections. There are no hidden operations to learn while using this design technique. However, such systems require users to be experts in the task domain.

Vincente and Rasmussen (1992) believe that the theories of DMI are not effective for complex human-machine systems. Experiments conducted by Rasmussen and Vincente (1989) support their belief that the DMI concepts do not effectively address the challenges of complex work domains. Additionally, Hutchins et al. (1985) point out some of the other disadvantages with this design technique.

DMI systems have difficulty distinguishing the representation of an individual element from a group of elements. DMI systems are faced with the problem of accuracy causing the user to manually control certain actions which would otherwise be handled by algorithms or methods built into the systems. The fundamental concept of such systems restricts users only to do, think, and interact with an application domain in ways that people generally know. These systems limit the computational flexibility provided to the users and thus prevent the users from exploring or finding new problems/constraints/solutions in the application domain. The opportunity to use new technology and learn more regarding the application domain is eliminated. If the user is a novice in the particular domain, then, it
would take a significant amount of learning time to master the DMI system. DMI systems do not assist the user in overcoming problems due to poor understanding of the task domain.

DMI systems have been implemented in supervisory control of Flexible Manufacturing Systems (FMS) (Benson et al., 1989) and NASA satellite ground systems (Pawlowski and Mitchell, 1991). In the FMS scenario (Benson et al., 1989), the multiple page keyboard-controlled interfaces were replaced with a single page mouse-controlled interface. However, experiments conducted in evaluating the new interface failed to show a decrease in uncompleted tasks. A reason for no improvement could be the single page interface itself; all entities are represented side-by-side on the same screen which can cause confusion in selecting the correct entity and hence delay in conducting/completing the task. Pawlowski and Mitchell (1991) designed a DMI for the NASA satellite ground systems based on a set of design principles and using the OFM model. This DMI system was designed to help operators perform a supervisory control task as well as enhance the intent inferencing capability of the operator’s associate. The suggested interface design principles for effective supervisory control were:

- a hierarchical modeling approach would reduce the scope of the problem,
- abstract relationships among resources should be made visible,
- interface can be used as an external memory to reduce the operator memory load,
- operator actions should be kept at skill- and rule-based levels of behavior; the system should support knowledge-based behavior for problem solving,
- interface should be designed for high visual momentum (Woods, 1984) which will allow the users to find as much required information as possible across the displays and combine all available information for obtaining effective solutions to problems.
**General user interface design guidelines:**

Norman (1983) suggested design rules based on analyses of human error. A couple of error types and the related design rules are explained below.

a) Avoid mode errors: Mode in this context is the system state. Mode errors accumulate when performing an action that is appropriate for one mode while actually residing in another mode. Such errors occur because the operator believes that the system is in one state (mode), while actually in another state. It occurs from poor indication to the operator of the system state. In complex systems, eliminating mode errors may be impossible, therefore

- Make sure that the system modes are distinctively marked, and
- Make the command required for executing action different for different modes.

b) Avoid description errors: Such errors occur when there is not enough specification to the system operator about how to perform an action. The operator performs a faulty action on the system that causes a serious problem to the entire system. This error type can occur even when the required list of functions to be performed for executing an action are provided. If the functions to be executed for one action are not provided in the correct order, performing a later function ahead of other functions could affect the system performance. In avoiding these errors in computer systems,

- Screen display and the menu system should be organized functionally,
- The menu display headings should be distinct from one another, and
- Make certain actions difficult to execute or non-executable because, these actions if performed can lead to serious implications and may not be reversible.
Smith and Mosier (1986) laid out a set of rules for displaying necessary data to the user:

- Display the data in a usable form,
- Display the data consistent with user convention,
- Maintain a consistent display format from one display to another, and
- Use consistent and familiar wording.

Molich and Nielsen (1990) devised nine general guidelines for user interface design:

1. Use simple and natural language,
2. Speak the user’s language,
3. Minimize user memory load,
4. Be consistent,
5. Provide feedback,
6. Provide clearly marked exits,
7. Provide shortcuts,
8. Provide good error messages, and

Shneiderman (1998) discusses eight golden rules of interface design. These rules are very similar to the rules put forth by Molich and Nielsen (1990). The eight rules are:

1. Strive for consistency,
2. Enable frequent users to use shortcuts,
3. Offer informative feedback,
4. Design dialogs to yield closures,
5. Offer error prevention and simple error handling,
6. Permit easy reversal of actions,
7. Support internal locus of control, and

2.11.3 Abstraction Hierarchy (AH)

The abstraction hierarchy (AH) was proposed by Rasmussen (1986) for the design of human-machine interfaces for fault finding in electronic workshops and supervisory control of nuclear power plants (Lind, 1999). This representation was designed to provide operators with information for coping with unanticipated events that can occur in complex human-machine systems. In an AH, higher levels of the hierarchy are less detailed than lower levels. Higher levels represent relational information about the system purpose, while the lower levels represent more elemental data about physical implementation (Vincente and Rasmussen, 1992). The exact number of levels and their information content will vary by domain based on the domain specific constraints. The information content at each level along with the interface structure provides the foundation for interface design.

The AH belongs to the set of hierarchies (Vincente and Rasmussen, 1992) whose properties are:

1. Each level of the hierarchy deals with the same system, the only difference being that different levels provide different models for observing the system,
2. Each level has its own set of concepts and principles,
3. The selection of the level for describing the system is dependent on the user, and his knowledge about and control of the system,
4. Proper functioning of the system at any level is imposed as meaningful operation on the lower levels of the hierarchy, and
5. As one moves up the hierarchy, a deeper understanding of the system with respect to the goals can be achieved; while on moving down the hierarchy, detailed explanation on how the goals can be carried out is obtained.

The AH is represented using multiple levels of means-end and part-whole abstractions (Nagel, 1979). The means-end abstraction describes how, in a work domain, the physical resources and system functions can be organized into five levels. Each level defines the means for the next higher level and defines the end that is completed using items on the lower level as the means. This means-end systematic framework helps in identifying and evaluating alternative courses of action and thus reducing the complexity of decision making in supervisory control tasks (Rasmussen, 1986). The part-whole abstraction decomposes or aggregates items on each level of the means-end abstraction.

The AH is goal-oriented (Vincente and Rasmussen, 1992). Using the means-end relationship and initiating the problem solving process at a high level of abstraction makes it easy to determine and concentrate on system parts that are of interest and pull out the sub-tree of the hierarchy which is relevant to the current goals. Parts of the system not relevant to the particular goals of interest are ignored.

Vincente and Rasmussen (1992) mention that other hierarchical representations do not use the means-end relationship concept. In these other hierarchies, the links between the different levels might not be completely goal-oriented. Although the entire system could be observed at the highest level of abstraction and the subsystems of interest for problem solving could be chosen, the sub-tree of the hierarchy connected to the subsystems of interest might not explicitly contain system components relevant to the goals.
Lind (1999) identifies some of the problems in constructing and using the AH modeling approach for complex systems especially power plant models. First, the AH model assumes its users are domain experts. Second, AH models are not flexible. Suppose there is some problem with an initial AH model of a work domain, it is very difficult to revise and modify the model. There is no method established in the AH framework to conduct the required modification. Third, the quality of decision making is dependent on the structure of the system provided by the means-end levels. If the levels are improperly defined, it will result in wrong decisions. If the levels are too abstract, certain decision alternatives could be overlooked. If the levels are too detailed, then irrelevant decision alternatives could be included. Lind (1999), therefore, suggests that the methodology provide explicit guidelines for identification of means-end levels and their relationships.

2.11.4 Ecological Interface Design (EID)

Ecological interface design (EID) was first proposed by Rasmussen and Vincente (1989) to describe the relationship between different classes of errors and the effect of those errors on the interface design. It is a theoretical framework for designing interfaces for complex human-machine systems based on the skills, rules, knowledge (SRK) taxonomy (Rasmussen, 1983) and the abstraction hierarchy (AH). The SRK taxonomy helps in developing a single design to support all three levels of cognitive control: skill-based behavior (SBB), rule-based behavior (RBB), and knowledge-based behavior (KBB). The EID framework extends the benefits of DMI to complex work domains assisting the operator during all conditions, especially during unanticipated events (Vincente and Rasmussen, 1992).
The intent of SBB on EID is to support the operator in directly acting on the display, with the information displayed in similar pattern to the part-whole structure of movements (Nagel, 1979). Implementing the part-whole structure on the interface display means designing the interface in a hierarchical visual structural manner so that the integration of elementary level visual features can lead to higher level cues for complex tasks. In the design of EID, RBB provides a one-to-one mapping between the domain constraints and the visual cues provided by the interface. Finally, the KBB represents the domain as an abstraction hierarchy (AH) that serves as an external mental model supporting knowledge-based problem solving.

Two fields in which the EID approach has been applied are neonatal intensive care medicine for patient tissue oxygenation (Sharp and Helmicki, 1998), and command and control for engagement planning in high pressure scenarios (Groskamp et al., 2005).

2.11.5 GOMS Model

GOMS (Card et al., 1983), an abbreviation for Goals, Operators, Methods, and Selection Rules, is a formal predictive modeling technique for interface design developed based on the cognitive problem solving behavior (Eberts, 1994). The GOMS model attempts to identify the goals of the user, how these goals are decomposed into sub-goals, and how and what kind of observable behavior can be used to satisfy these goals.

The components of the GOMS model are:

G of GOMS: represents the goals of the task. Card et al. (1983) describes a goal as a symbolic structure for defining a state to be achieved and determining a set of possible
methods to accomplish it. A goal contains information about what is desired about the methods available and what has already been tried.

O of GOMS: represents the operators. Card et al. (1983) defines operators as elementary perceptual, motor, or cognitive act whose execution is necessary to change the user’s mental state or affect the task environment. The user behavior is composed of the serial execution of operators. The observable behaviors such as keystrokes, mouse movements, and user movements are dependent on the desired task analysis (Eberts, 1994).

M of GOMS: represents the methods. Methods describe the procedures available for achieving the goal in terms of the operators and other sub-goals. Users involved in the task usually have a choice of many different methods.

S of GOMS: represents the selection rules. The selection rules are the control structure of the model. In order to define the user behavior properly, the available choice of methods have to be represented in the model. Selection rules such as if-then rules are used in methods representation.

Applications where GOMS model has been extensively used include the modeling of word processors (Card et al., 1983) and in modeling the CAD system for ergonomic design (John and Kieras, 1996a).

2.11.6 Cognitive Task Analysis (CTA)

Cognitive Task Analysis (CTA) is a methodology to capture the knowledge and processing model used by experts in performing their jobs in complex, dynamic, real-time environments (Gordon and Gill, 1997). Such a knowledge model can be used in developing system interfaces, decision aids, and training programs. Redding (1992) defines CTA as an
approach in determining the mental processes and skills required in performing a task and the changes that occur as the skill develops.

CTA is a very time consuming task and is usually restricted to

a) complex, ill-defined tasks that are difficult to learn,

b) complex, dynamic, uncertain, real-time environments, and

c) multi-tasking, where the person will have to perform more than one task simultaneously.

Gordon and Gill (1997) briefly explain some of the techniques that have been developed and used by researchers performing CTA. These techniques are Concept Mapping and Expert Design Storyboarding, COGnitive NETworks of tasks (COGNET), Conceptual graph analysis (CGA), and Precursor, Action, Result, and Interpretation (PARI) method.

Concept Mapping and Expert Design Storyboarding are two methods used in the development of the required CTA knowledge base for a task (McNeese et al., 1995; Zaff et al., 1993). In concept mapping, an analyst works with an expert in unstructured interviews to draw concept maps. The concept maps consist of unstructured graphs containing concept nodes and interrelated with labeled links which help as memory aids in eliciting knowledge from the expert. The graphs from multiple experts are combined to finalize on a concept map for a task. After deciding the concept map, the experts are involved in storyboarding an interface design which consists of drawing sequence of sketches showing the interface design for the task under study.

COGnitive Network of Tasks (COGNET) is a methodology that assists in modeling human-computer interaction in complex decision making tasks where the users must share their attention among multiple tasks (Zachary et al., 1993). The framework attempts to model
the expert behavior in their information processing for completing the required tasks. The COGNET model is then computationally refined and executed to perform decision making processes using built-in agents.

Conceptual graph analysis (CGA) consists of both a representation method called conceptual graph structures (Graesser and Clark, 1985) and a set of knowledge acquisition methods (Gordon et al., 1993). Conceptual graph structures are semantic networks in which the nodes might be simple concepts and can also be complex events or actions which are linked together by labeled arcs. The knowledge acquisition methods are developed to help in the development of the graph structures. The order in which these methods are performed are: document analysis and unstructured interviews to get information to start a graph, structured interviews using probe questions, recording multiple experts performing a variety of task scenarios in real or simulated environments and finally reviewing the finding by the analyst and expert together. All the information is finally converted into graphical form by the analyst.

The Precursor, Action, Result, and Interpretation (PARI) method has been used to perform CTA on complex and ill-structured tasks (Gott, 1989). Initially, experts are asked to generate problems familiar to them. Each expert is then paired with another expert who begins to solve the problem. An expert’s work is recorded, they are asked questions and also asked to draw diagrams giving insight into the mental model problem. Finally, the analysts and experts together identify precursors, actions, results, and interpretations from the analyses. Such analyses helps in identifying several types of knowledge such as declarative or system knowledge and strategic knowledge which is top-level knowledge about making decisions on when to perform various procedures.
3. GAPS IN EXISTING KNOWLEDGE

This chapter recounts unexplored research areas and areas where the surveyed research did not yield the expected results when applied to a complex, dynamic, time-critical, dual-task scenario environment with an individual decision maker. Specific focus is provided to interface design and display characteristics in such an information rich context.

The need for interface design guidelines and display components continues to exist.

1. Individuals need to maintain SA, need to perform mental simulation using available cues, and need to make timely decisions. Under conditions of rapid decision making, they may not have the time to generate alternative solutions and choose the best solution. Studies conducted by Brunswik (1956) and Hammond et al. (1987) suggest that under time pressure individual performances are better when using perceptual reasoning than when using analytical reasoning. Kirlik (1989) supported these findings and found that people tended to use analytical reasoning only when they had to make decisions with insufficient information about the domain. Klein’s (1989a) work also supports these findings and shows that the RPD model assists users in making quick decisions and coping with time stress.

2. Irrespective of whether the individual is an expert or novice in the domain, under high time pressure and information uncertainty, the judgement and decision making of individuals is not very accurate (Kerstholt, 1994).
Figure 1: Research problem focus
Figure 1 illustrates some of the problems that must be addressed in the domain of dual-task scenarios for individual decision making. The figure applies to a time-critical, rapid decision making, dual-task scenario environment, where both the primary and secondary task scenarios are equally complex with respect to the amount of information, and the entire system must be handled from a small screen display by a single decision maker, and only one task scenario can be controlled at any instant. There are certain issues that must be addressed for effective user performance in such scenarios: how to enable rapid situation assessment, how can the alert system effectively notify the user about the interrupting secondary task, what are the effective data presentation formats for rapid decision making tasks, and how can the primary task be resumed quickly after returning from an interruption. The designer is also faced with the problem of how to design the secondary display interface which is also loaded with information.

Interface design methodologies are somewhat limited for designing interfaces for dual-task environments. Methodologies such as the abstraction hierarchy (AH) are suitable only if the operators in the domain are experts as both operators and decision makers. To extend AH will require as many sub-AHs as the number of tasks scenarios. The overall AH structure might be too complex for the designer to interpret and implement into an interface, and direct manipulation interfaces (DMI) require providing sufficient training to the operators. Some of the other methodologies, such as the OFM and CTA, can be used for defining the system states and operator functions in the particular domain. The OFM represents the multiple concurrent tasks performed by an operator in one single complex system (Mitchell, 1987).
Other than work by Krosner (1991), research does not seem to exist wherein the OFM method, or other methods, have represented multiple different complex systems controlled simultaneously by a single operator with each system requiring performance of multiple concurrent tasks. While the OFM model does not give much support to the operator in determining the cognitive complexity in a system, GOMS does not represent multi-task management and cognitive complexity in a system and it is not evident whether CTA methods can be used for human-in-the-loop simulation (Anastasi et al., 1997). These above-mentioned interface methodologies do not define a generic set of interface specifications such as size, location, and color codes that can be used in the display design process. Human factors/user interface design guidelines do exist (Smith and Mosier, 1986; Molich and Nielsen, 1990; Shneiderman, 1998). In the past, research conducted on dual-task scenarios have neither applied nor evaluated these guidelines. If we consider a small screen display, with map display, geo-plots or radar display required for both task scenarios in a dual-task set-up, what are the human factors/ user interface guidelines that should be followed for effective task performance?

Extensive research has determined what information format appears superior to the other formats in assisting decision makers complete their tasks in a problem scenario. Most of the time, the researchers have concluded that graphical and three-dimensional representation is better than tabular and numerical representation (Vessey, 1991). However, in dual-tasks environments, no research seems to exist that has specifically looked at determining the most effective information presentation formats. Can the knowledge from previous research on single-task scenarios be extended to dual-tasks scenarios? Would it yield the same kind of results?
How does the complexity increase, when a single individual has to handle, even concurrently, completely different scenarios of similar complexity, where complexity is defined with respect to the information richness? Multi-tasking by a single individual is difficult. If all the task scenarios are complex, time-sensitive and extremely information rich, the level of difficulty increases. Irrespective of whether the individual operator responsible for performing the tasks is a novice or expert, operators generally prefer all the information for each task be presented to them in a quickly understandable manner. For single-task scenario environments, researchers have implemented status-at-a-glance displays that can assist the operator in quick assessment of the situation (Shafto and Remington, 1990; Potter et al., 1992). Woods and Watts (1997) proposed a set of guidelines for constructing such status-at-a-glance displays. Although the status-at-a-glance guidelines mention that raw data describing the system components are not the only information that should be displayed, they do not provide further details on what will be the features of such a display when used in a static task environment or when used in a dynamic task environment. How should interface display components such as status-at-a-glance be adapted for a dual-task scenario environment, especially when the secondary task scenario is also rich with information? A limited amount of research has examined this issue.

It has been found that increasing the amount of information, such as increasing the number of vehicles monitored by a single user, causes an increase in the errors of omission (Cummings, 2005). Edmonds (1999) points out that increasing the number of entities to monitor, increases the cognitive complexity. As time pressure increases, the number of decisions made decreases and the number of correct decisions made also decreases (Cummings, 2005). Errors of omission, also increases with an increase in the number of color
categories used in the display. With more color categories used, the user might spend more time on a searching or a mapping task (Cummings, 2005). No more than seven colors should be used to define information in all the displays for a system (Shneiderman, 1998). Use of many color combinations causes cognitive tunneling or inattentional blindness (Simon, 2000). This is the condition where the user might miss other important information on the display because the person might be fixating their attention on the more salient color change. *Studying the effect of color categories in dual-task scenarios is essential and has not been fully examined.*

Usually, in dual-task scenarios, the user is interrupted during the primary task and asked to perform the secondary task. After completing the secondary task, the user returns to the primary task and resumes the work (Bailey et al., 2001; Bartram et al., 2003; Katsuyama et al., 1989; Trafton et al., 2003). Generally, it is believed humans create a mental model of the scenario in which they are working. As the scenario becomes information rich, it is difficult to maintain a robust mental model. Due to interruptions and information abundance, the ‘working memory capacity’ of operators might gradually degrade. In dual-task scenarios, the ‘long-term memory’ of the operators might also be affected. Research has begun to examine providing visual cues to the operator of a monitoring task and determining their effectiveness in helping the operator detect and identify all the changes that occurred in the dynamic environment during the interruption period (Smallman and St. Johns, 2003; St. Johns et al., 2005). *Successful change detection need not necessarily mean that the operator has good SA of the system and can resume the primary task effectively. Research must be performed to determine the visual display cues that should be provided for rapid situation assessment of the entire system as well as resumption of the primary task after interruption.*
Can such visual displays also effectively aid the operators to forecast the status of the scenario at some point in the future?

When the display for both the primary and secondary tasks are shown using the same display unit screen, the secondary task display has always been a small window. Alternatively, the secondary task was performed on a display unit different from the primary task display unit. In such a case, the display units were placed close to each other. One particular study examined the azimuth level of the display unit presenting the secondary task with respect to the position of the operator (Katsuyama et al., 1989). McFarlane (2002) and Trafton et al. (2003) conducted dual-task studies in which the display screen of only one task (primary or secondary task) are viewed at a time. In such cases, the operator must completely switch between the tasks scenarios and will lose complete visual focus of one of the task scenarios. In the research on adaptive automation (Kaber and Riley, 1999), the users did not need to switch between displays. They could view both the task displays simultaneously. However, in above-mentioned research studies, the users spent less than a minute working on the secondary task. Past research does not seem to have required the users to perform a secondary supervisory control task that was as complex as the primary task and the secondary task prolonged for close to 4 to 5 minutes. Such an experimental set-up would definitely affect the short-term memory capacity of the system users. Further, the cues for primary task resumption should be well designed so that in spite of the large interruption period, the task resumption lag is kept at a low value.

Secondary tasks have involved studying the effect of scrolling one-line or two-line text or tickers or faders (Maglio and Campbell, 2000). Such details of the task are fixed to a small area on the display screen and are of a specific font size and color. However, if the
secondary task involved monitoring city traffic at peak hours or UAV search and identify, then we will have objects moving over a large part of the screen on a spatial display unit. The effect of animation such as moving images or changing icons such as those of UAVs or other system entities have not been studied in the secondary task scenarios in a dual-task environment. How can the interface be designed so that operators can handle animation and changing icons in the secondary task and hence maintain situation awareness and not be affected by change blindness or inattentional blindness?

It was also found that, for the secondary task, as the position (location) of the display component and its area on the screen changed, the performance of the human significantly deteriorated. With such knowledge from the literature, if we set-up an experiment where both the primary and secondary tasks scenarios are complex and information rich, the position and size of every information source on the screen has to be given equal importance. Since, no research seems to have examined highly complex dynamic secondary tasks on a small screen display, the determination of position and size of the display components and the relevant visual cues is also a research area.

In dual-tasks scenarios, alert mechanisms are used to notify the operator that a secondary task is waiting that needs attention. These alerts on small screen displays have generally been flashes, changing tones, and countdown timers (Trafton et al., 2003). Multi-modal alerts such as fire alarms or any other audio-visual signal, though have been used in real world, the effectiveness of such alert techniques have not been tested in small screen complex dual-tasks scenarios visual display interface. How will multi-modal alerts, specifically audio-visual alerts affect the human task performance in small screen complex
dual-task scenarios? Does the size and location of the alert on the display screen have a significant effect on the performance?
4. RESEARCH METHODOLOGY

Chapter 2 reviewed the pertinent literature from which chapter 3 detailed those aspects of the dual-task domain requiring additional research. This chapter provides the resulting research questions addressed in this research and the research methodology employed.

4.1 Introduction

This research effort studies the effect of interruptions on team performance, assesses design user interface components for dual-task scenarios environment, and examines the effect of interruptions on a single operator managing two complex dynamic time-critical task scenarios. Visualization methods are developed for a time-critical information rich dual-task scenario environment and user interface guidelines for such dual-task scenarios are proposed. The objective is to provide the human operator a visual interface that helps maintain situation awareness, reduce mental workload, rapidly re-assess and resume an interrupted primary task, eliminate change blindness (Durlach, 2004) and eliminate inattentional blindness (Varakin et al., 2004). Change blindness is a condition where the operator has difficulty detecting changes in the features or parameters of objects depicted on the display screen, even when the object that is being attended to is changing (Durlach, 2004). Inattentional blindness is a condition where the human operator sometimes fails to detect that a particular
system object has been left unattended, even when that object is located close to the system object or situation being attended to at that time (Varakin et al., 2004).

4.2 Methodology

The research methodology employed uses a three-stage process:

Stage 1 (Experiment 1):
The first stage study examines the need for visual cues. An existing software (video game) is used to study the effect of interruptions on trust and coordination between members in small virtual teams.

Stage 2 (Experiment 2):
In the second stage, an initial set of user interface design guidelines are proposed and visual cues are designed. Experiments are conducted to study the effect of interruptions on individuals when they are provided with these additional visual cues.

Stage 3 (Experiment 3):
In the third stage, alerts or warning signals are designed and implemented in the user interface to notify the individual regarding an impending interruption and how the alert will affect the performance in primary task.

For the second and third stages of the research, the approach followed uses scenario-based interface design. Pre-defined scenarios are used to design the interface, and its components, for both the primary and the secondary task. Both the primary and secondary task scenarios focus on the Unmanned Aerial Vehicle (UAV) domain. The primary task scenario is the monitoring and control of Uninhabited Combat Aerial Vehicles (UCAVs) on a search and destroy mission and the secondary task scenario is the routing and control of
UAVs on a reconnaissance mission. Such a dual-task scenario is specifically formulated to determine whether a single operator can handle simultaneously two different UAV and UCAV missions, conducted in geographically different regions, and what are the effects on operator task performance.

The research framework for the second and third stages is illustrated in Figure 2. In this research study, the important research component addressed is the user interface for assisting an individual human operator in monitoring and controlling two task scenarios serially as depicted in Figure 3. In this research, two sets of user interfaces are designed, a baseline user interface and an advanced user interface employing more visual cues. Both interface designs are tested in experiments involving human participants.

**Figure 2:** Research framework
The baseline user interface set contains two primary components: an interactive spatial map displaying system entities and an interactive information panel displaying the entities properties and other system related parameters. System users use the baseline interface to monitor and control the UCAVs or UAVs and perform assigned tasks in the dual-task environment. The baseline user interface is based in part on past studies (Narayanan et al., 2000; Cummings, 2003).

The advanced user interface set involves supplementing the baseline user interface with additional visual components to assist the users in their tasks. The visual displays are designed using the interface design guidelines produced in this research (see section 4.5). The visual display features of the user interface includes a status display that updates the human about the system performance at-a-glance, alert technique to inform the human about a waiting secondary task, planning cues for assisting the operator in decision making and understanding the future system status based on their current actions, interruption recovery and resumption cues for assisting the operator in resuming their interrupted initial task.
(primary task), and the spatial map displays or geo-plots. Both the baseline and advanced user interface designs incorporate color-based and icon-based cues.

4.3 Research Questions

The study addresses the following research questions:

1. Due to interruptions, is there an effect on performance and hence an effect on trust and coordination between members of a team?
   a. Despite interruptions, do the teams performing situation awareness calibration, successfully complete more missions than other teams?
   b. Despite interruptions, do the teams performing situation awareness calibration, complete the missions in less time compared to the teams not performing the calibration?
   c. Does performing situation awareness calibration in an interruption-laden task scenario, help in maintaining a higher level of trust between team members?

2. Does providing advanced visual cues enhance operator situation awareness and task performance in dual-task environments?
   a. In the primary task, does the status-at-a-glance display and message log assist the human operator in rapidly attaining situation awareness and perform tasks?
   b. Does the status-at-a-glance display in the secondary task scenario assist the operator in rapidly attaining situation awareness?
   c. Do visual display cues for solution exploration events assist the human in effectively and quickly conducting planning tasks?
3. How can the human ability to resume an interrupted task be enhanced in dual-task scenario environments?
   a. Does the advanced user interface assist the operator to quickly resume primary task compared to the baseline interface?
   b. Does the complexity of the secondary task affect the time taken to resume the primary task?
   c. Does the similarity of the secondary task to the primary task affect the time taken to resume the primary task?
   d. Does the advanced user interface assist the operator obtain change awareness quickly in the primary task compared to the baseline interface?
   e. Is secondary task resumption comparatively faster when using the advanced user interface display compared to the baseline interface?
   f. Does the presence of advanced user interface tools significantly reduce the change awareness time in the secondary task compared to the baseline interface?
   g. In a dynamic dual-task condition, does the advanced user interface help the operator maintain a relatively lower mental workload compared to the baseline interface?

4. Is the use of alerts or warning signals effective in notifying operators about a secondary (interrupting) task without degrading the performance in the primary (interrupted) task?
   a. Does the nature of the alert (visual alert to audio-visual alert) influence the time taken by the human to detect notification regarding the impending secondary task?
b. Does the nature of the alert (visual alert to audio-visual alert) affect the operator’s ability to stay longer on the primary task before switching to the secondary task?

c. Does the time in the primary task during the alerting phase help the operator quickly resume the primary task on return compared to resuming the primary task after being abruptly interrupted?

d. Does the time in the primary task during the alerting phase help the operator gain change awareness more quickly compared to the condition of being abruptly interrupted from the task?

e. Does the nature of the alert (visual alert to audio-visual alert) affect the operator’s frustration level?

The next section describes the domains in which these research questions are examined. Research question 1 is examined using the domain of sense and respond logistics (SRL) while the last three research questions are examined using applications in the domain of Unmanned Aerial Vehicles (UAVs).

4.4 Domain Description

Real world situations are complex and dynamic in nature. Examples include domains such as unmanned aerial vehicles, medicine, ocean floor investigation, industrial systems, and space exploration. A complex system (Rouse, 2003) is formed of multiple elements, consists of a large number of interactions and relationships between these elements and involves uncertainties associated with these elements and their relationships. Irrespective of the field of operation, the accuracy, timeliness, and quality of information provided to the decision maker involved in a complex task is very important.
4.4.1 Sense and Respond Logistics (SRL)

Modern decision making, through the use of information technology, is becoming more distributed and more often involves multiple decision makers. Workers in power plants, management administrators, and officials in command and control situations often collaborate and coordinate their decision making activities while interacting with computer-based systems. Such activities are viewed as collaborative decision making (CDM) tasks (Coury and Terranova, 1991). One key benefit often associated with any collaborative effort is better collective knowledge of the current conditions in the scenario via sharing of information and hence improved understanding of the challenges to complete a task. Often through group evaluation of a situation, more effort is expended to avoid mistakes in decision making. CDM is a core competency of effective team performance, and incorporates communication, cooperation, and coordination (Coury & Terranova, 1991). Time is also an important factor in decision making. Decision makers require information to make appropriate, timely decisions. Collaboration among team members cannot effectively occur under the pressure caused by communication failure.

SRL is one such distributed collaborative decision making activity. Small groups of logisticians, each located at potentially different geographic coordinates and possibly working in different time zones must plan, coordinate, and execute logistic operations. Under normal conditions, these operations can often be successfully completed on time. However, when SRL operations must be executed in a war-like scenario, the missions must be more flexible and may often adapt based on unexpected events. Among SRL issues are that SRL tasks often do not involve face-to-face communication, each team member may not be
familiar with the computer-based systems they are using, and they may not even know personally the team members with whom they must interact. Therefore, trust among team members can play a key role in the eventual success or failure of any SRL process. For an SRL process to function effectively, team members must be provided with information technologies that support and enhance the distributed decision making process. One such medium for communication is a textual chat tool to communicate and share information among team members collaborating via the computing system.

4.4.2 Unmanned Aerial Vehicles (UAVs)

Remotely operated vehicles, such as the UAV or the UCAV, are used extensively in this age of Information Warfare (IW) (Flach et al., 1998). The UAVs are controlled via collaboration between the human operator and automatic control systems (Drury and Scott, 2008). This is an example of a multi-task telerobotic control systems (Flach et al., 1998; Sheridan, 1992). This section outlines an analysis on the domain of UAV throwing light on certain applications of such vehicles to date.

UAVs obtain images of battleground movements that are later compared and matched to an image database for transformation into three-dimensional (3D) views. The US Navy has developed video reconnaissance systems that combine video and telemetry data obtained from UAVs with information stored in databases (Hardin, 2002). This fusing of all relevant information provides a video system with command-and-control data that field commanders can understand and use to make decisions. Airborne and space-based literal imaging systems have increased area collection capabilities and the ability to locate targets accurately. UAVs mounted with video cameras, support weapon targeting (McConnell, 2001) and also assist in
inspection, monitoring, surveillance, disaster mitigation, and search-and-rescue. They are also used in the suppression of enemy air defenses (SEAD) (Barbato et al., 2002).

According to Department of Defense, Joint Chief of Staff Publication 3-01.4,

“SEAD are missions that neutralize, destroy, or temporarily degrades surface-based enemy air defenses by destructive and/or disruptive means. It requires planning, coordination, and rapid tactical responses to successfully attack on enemy’s Integrated Air Defense System (IADS) in support of friendly forces”.

Barbato et al. (2002) mention that among the objectives of the Air Force Research Laboratory Human Effectiveness Directorate are efforts to quantify UAV control station requirements for SEAD missions by 2015 and to evaluate whether automatic or manual function will allow operators to simultaneously manage multiple UAVs. AFRL is also involved in conceptualizing and designing operator-vehicle interfaces that integrate control/display technologies and decision-aiding features so that the human operator and the UAVs can successfully accomplish all mission requirements.

The Low Elevation Aerial Photography (LEAP) system was developed to overcome obstacles prevalent in time-critical dynamic environments such as in disaster mitigation and urban search and rescue (USAR) environments (Green and Oh, 2003). The LEAP is an easy-to-fly, backpackable, quickly deployable, lightweight system that carries a teleoperated vision system for acquiring images. The system with inbuilt image processing techniques was integrated with wireless networking for rapid acquisition and distribution of images to command and control centers.
The MITRE Corporation developed a ModSAF-driven model for a UAV provided with a moving target indicator (MTI) radar for surveillance, and a Battlefield Combat Identification System (BCIS) for correct identification of friendly forces (Pierce, 1998). Real-time rendering of the images were performed by integrating the UAV model with visualization software. This model is used in stations that control the multisensor UAV imaging tasks which take place when an MTI track is selected.

An unmanned aerial helicopter has been used in surveillance operations for aiding ground patrolmen in discovering illegal dumping activities in remote areas around the river bank in the Taoyuan County in Taiwan (Chen, Chen, and Wu, 2001). The unmanned helicopter is equipped with GPS, digital camera, and river-associated GIS. The vehicle provides aerial data of the suspected dumping spots while the GIS is used to produce a spatial information system for integration of the aerial video images with the related digital data. Researches that have been explained earlier are related to UAVs that are flown outdoor and ground-based mobile robots.

A typical UAV domain will include the entities listed in Table 1, entities that include the vehicle, targets, and the terrain. Each entity has attributes. At a particular time, each entity will have a behavior or state associated with them and there are various events that each entity performs (Banks et al., 1996).
<table>
<thead>
<tr>
<th>Entity</th>
<th>Attributes</th>
<th>States</th>
<th>Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle</td>
<td>ID, Start location, current location, speed,</td>
<td>stationary, at base, moving from one waypoint to another waypoint</td>
<td>1) leave base</td>
</tr>
<tr>
<td></td>
<td>altitude, route</td>
<td>(destination), loitering (searching for target), returning to base</td>
<td>2) move towards first waypoint</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3) find target</td>
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<td></td>
<td></td>
<td></td>
<td>4) identify target</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>5) if enemy, deploy specific missile</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>6) reach waypoint</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>7) loiter</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>8) move to next waypoint</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>9) perform steps (3) to (7)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>10) reach the final waypoint</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>11) go to base</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>12) re-fueling</td>
</tr>
<tr>
<td>Human</td>
<td></td>
<td>monitoring vehicle movement, rerouting vehicle path,</td>
<td>1) start mission</td>
</tr>
<tr>
<td>operator (supervisor)</td>
<td></td>
<td></td>
<td>2) monitor vehicle status</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3) route vehicle to targets</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4) Evade destructive objects/regions</td>
</tr>
<tr>
<td>Target</td>
<td>Location, distance from vehicle, mobile,</td>
<td>Identified, unidentified, stationary</td>
<td></td>
</tr>
<tr>
<td></td>
<td>immobile, target type (friend or foe)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Terrain</td>
<td>size, boundary coordinates, obstacles on the</td>
<td></td>
<td></td>
</tr>
<tr>
<td>terrain</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No fly zone</td>
<td>Size, location or coordinates</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sensor</td>
<td>ID, range, detection accuracy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weapon system</td>
<td>ID, range, type, hit ratio</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
For interface design, it is important to know what information is needed by the operator to perform each task supported by the system. The operator needs full information about all entities in the scenario. Entity parameters for each entity modeled as a part of the overall design is based on Table 1 which lists the attributes of each entity, and their behavioral states. The common features in a UAV supervisory control visual display is based on past studies of that domain (Narayanan et al., 2000; Cummings, 2003). For example, for monitoring a scenario in the UCAV domain, the operator needs information about the UCAV and its components such as the sensors and weapons, the targets information, and information about other objects present on the terrain such as the base and no-fly zones. Visually, these objects are presented on a spatial map display as dynamic or static objects. Clicking on a particular object displays its parameters on a side panel. Entity parametric information is also displayed as a tool tip feature.

The current research interface is designed on an existing UAV testbed called the Multiple Unmanned Aerial Vehicles in a Virtual Environment System (MUAVES), designed and developed in the Human Computer Interaction (HCI) Lab and the Advanced Modeling Optimization, and Systems (AMOS) Lab at Wright State University. A snapshot of the MUAVES user interface is in Figure 4. Figure 4 shows 3 UAVs originating from a base and following their pre-assigned route. Targets are represented in the form of small red squares on the user interface. On the right side of the map display, a particular UAV can be selected from the drop-down list and all its properties are displayed in the properties window. The operator can change the UAV properties via the properties window in the user interface.
There are five primary user interface interaction styles (Shneiderman, 1998). These styles are direct manipulation, menu selection, form filling, command language, and natural language. Among these five styles, the direct manipulation style is used in this interface design because direct manipulation is easy to learn for novices and, with training, allows users to perform tasks rapidly, a requirement for this research.

**Figure 4:** Snapshot of an UAV simulation designed for the MUAVES architecture
4.5 Visual Display Guidelines and Visualization Techniques

4.5.1 Initial proposed user interface design guidelines for dynamic dual-tasks

The following guidelines for effective user interface design apply to dynamic, dual-task environments. The guidelines were developed based upon the basis of best practices and the critique of those practices as provided in Chapters 2 and 3.

1. An at-a-glance display to assist the operator to obtain information quickly and maintain situation awareness is a primary requirement. Both the primary and secondary task user interface will contain this at-a-glance display component.

2. Visual cues for quick and effective resumption of an interrupted task are provided in the primary task scenario interface, irrespective of whether the scenario is static or dynamic.

3. User alert techniques (uni-modal and multimodal alerts) that notify users regarding an impending interruption are designed. For example, animation only and animation with audio signal (beeping sound), are adapted to dual-task scenarios. However, the size and location of the alert is given importance.

4. The mode of interruption depends upon the situation and the interrupting task. If the interrupting task is a time critical event, it must be acted upon immediately. Research has shown that even if people are given the choice of handling the interrupting task at their convenience (negotiated interruption), they almost always wait until the end of the primary task to perform the interrupting task, which may not be acceptable. A better option is to use alerts to notify the operator of the secondary task. The appearance of the alert indicates to the operator that the system will switch to the secondary task after some time lag. This time lag, from the onset of the alert to the actual viewing of the secondary
The task display interface, is called the interruption lag time, during which the operator can try to stamp a pictorial representation of the primary task scenario in their memory.

5. In highly complex dynamic environments, if the primary task and the secondary task scenarios are unrelated, then do not show the secondary task display interface while operators are performing the primary task. It is preferable that no information about the secondary task is shared with the operator currently involved in the primary task scenario.

6. If the primary and the secondary tasks are related, and if the secondary task display contains additional information about components in the primary task, such additional information should be made available on the primary task interface. This information set can either be displayed permanently on some section of the interface, or if the information is something that need not be accessed all the time, it can be displayed on a collapsible window that when expanded, is docked with the main user interface and does not block other displays in the user interface.

7. Similar color categories should not be used in the primary and secondary task scenarios, especially if the color type is going to convey different information in the task scenarios.

8. Icons and symbols convey information quickly and more accurately to the human. System components should be represented as icons and changes in the state of the components should be shown by change in icon representation, thus extending work to dual-task scenarios.
4.5.2 Icon Representation

Icons have been successfully used in the depiction of dynamic and static objects that are present on a map display in a command and control scenario. For this research, the color of the icons and their shape for different status are provided in Tables 2, 3, and 4.

**Table 2**: Default colors for symbology (adapted from US DoD, 1996)

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>ICON (RGB VALUE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Friend, Assumed Friend</td>
<td>Cyan (0, 255, 255)</td>
</tr>
<tr>
<td>Unknown, Pending</td>
<td>Yellow (255, 255, 0)</td>
</tr>
<tr>
<td>Neutral</td>
<td>Neon Green (0, 255, 0)</td>
</tr>
<tr>
<td>Hostile, Suspect</td>
<td>Red (255, 0, 0)</td>
</tr>
</tbody>
</table>

**Table 3**: Icons depicting target information for primary task scenario (adapted from US DoD, 1996)

<table>
<thead>
<tr>
<th>BATTLE DIMENSION</th>
<th>ABOVE SURFACE</th>
</tr>
</thead>
<tbody>
<tr>
<td>AFFILIATION</td>
<td>AIR (A)</td>
</tr>
<tr>
<td>PENDING (P) (YELLOW)</td>
<td>🌸</td>
</tr>
<tr>
<td>UNKNOWN (U) (YELLOW)</td>
<td>🌸</td>
</tr>
<tr>
<td>FRIEND (F) (CYAN)</td>
<td>🌸</td>
</tr>
<tr>
<td>NEUTRAL (N) (GREEN)</td>
<td>🌸</td>
</tr>
<tr>
<td>HOSTILE (H) (RED)</td>
<td>🌸</td>
</tr>
<tr>
<td>ASSUMED FRIEND (A) (CYAN)</td>
<td>?</td>
</tr>
<tr>
<td>SUSPECT (S) (RED)</td>
<td>?</td>
</tr>
</tbody>
</table>
Table 4: Icon depicting target information for secondary task scenario

<table>
<thead>
<tr>
<th>BATTLE DIMENSION</th>
<th>ABOVE SURFACE</th>
</tr>
</thead>
<tbody>
<tr>
<td>AFFILIATION</td>
<td>AIR (A)</td>
</tr>
<tr>
<td>LOW PRIORITY TARGET (BLUE)</td>
<td>🔵</td>
</tr>
<tr>
<td>HIGH PRIORITY TARGET (RED)</td>
<td>🔴</td>
</tr>
<tr>
<td>MEDIUM PRIORITY (BLACK)</td>
<td>🔴</td>
</tr>
<tr>
<td>NEUTRAL (N) (GREEN)</td>
<td>🟢</td>
</tr>
</tbody>
</table>

4.5.3 Status-at-a-glance display

The status-at-a-glance display is designed both for the primary and secondary task scenarios as a display panel on the side of the map display. The status-at-a-glance display is not collapsible.

The design of the status-at-a-glance display involves displaying the information of each entity in the scenario one below the other and at the bottom of the display the terrain details are shown. Figure 5 depicts the status-at-a-glance display providing details of UAV1, UAV2, and the terrain.

For the primary task scenario, the display includes information about the UCAVs. On the status panel, the background color to the UCAV name is set to the same color as the color of that UCAV on the map display. Only critical parameters regarding the UCAV or UAV that are required by the controller to effectively monitor and control that vehicle are only displayed on the panel. The parametric values provided include health status (ratio), fuel remaining (in percentage), speed, location on the map, number of locations (waypoints) to visit on its assigned route, no of weapons remaining, number of assigned targets, distance
from base, number of targets detected, name of the last detected target, number of targets identified, and number of targets destroyed.

**Figure 5:** Snapshot of status-at-a-glance display depicting information of 2 UAVs

In addition to providing all the system related information, this display acts as an alert to the operator if there is an important issue that the operator has left unattended (unnoticed) for sometime. For example, if the UCAV is passing through a no-fly zone, and if the operator has not attended to it, the UCAV health status will begin to reduce. Once the health status dips below the perfect value, the background color of that particular UCAV’s health value will be colored red. This coloring acts as an alert to the operator to change the route (EVADE the no-fly zone) before the UCAV is completely destroyed. Also, if the fuel remaining percentage is dropping closer to the minimal quantity and there might not be enough fuel to
follow the assigned route, then the remaining fuel in the fuel bar is painted in red color. The operator must select that affected UCAV and select ‘Go to Base’ so that the UCAV stops its assigned route and begins to return to the base.

The status-at-a-glance display is also provided with the ‘tooltip’ feature. Using this feature, the user can obtain detailed information regarding the targets that have been detected, identified, and destroyed by an UAV. The user must place the mouse pointer over a particular label containing a numerical description, as a result of which a pop-up window containing related information would appear. In Figure 5, taking UAV2 information into consideration, the placement of the mouse pointer over the ‘number of identified targets’ label (which is 2) gives a detailed description of the targets identified by UAV2. The detailed description includes 3 parts: the name of the target, the initial state of the target, and the final state of the target. The tooltip also informs the total number of enemy targets in the identified list.

4.5.4 Message log display

The message log display is used in both the baseline interface and the advanced visual interface. The display is a window listing the log of events that have occurred or are currently occurring in the scenario. All messages are time-stamped. All text messages in the baseline are displayed in black color as shown in Figure 6. In the case of the advanced visual interface, the event logs are displayed in light brown color when the system control mode was ‘Manual’. During task switch, the primary task control mode is changed to ‘semi-automatic’. During this mode, new event logs are written in green color. Upon task resumption, the message log display displays all text messages relevant to events that
occurred during the interruption on a light background color as shown in Figure 7. The background color design is for easy change detection, upon task resumption.

![EVENTS LOG](image)

**Figure 6:** Snapshot of the message log display for the baseline interface

![EVENTS LOG](image)

**Figure 7:** Snapshot of the message log display for the advanced user interface
4.5.5 **Interruption recovery and task resumption – visual cues and elapsed events image viewing tool**

Resumption visual cues are displayed on the interrupted task or the primary task in a dual-task scenarios environment. The purpose of these visual cues is to help the operator recall the interrupted situation (status when interrupted to attend the secondary interrupting task) and understand how it has evolved over time (while performing and completing the secondary task). This display feature helps the operator obtain change awareness of the system components and retrieve a thorough situation awareness for the system. Earlier studies on resumption of task after interruption have only examined how the operator can recover system details from memory and progress ahead. However, if the primary task is dynamic in nature, then it is difficult for the operator to just rely on their memory of the scenario and continue with the remaining tasks.

Since the resumption visual cues can help an operator regain situation awareness, the cues, other than those shown directly on the map display, are presented as a part of the status-at-a-glance display.

For the operator to obtain change awareness quickly, the display interface contains an ‘Elapsed Events Image Viewer’ tool as shown in Figure 8. This tool displays images of the map scenario at different moments when an event was triggered or an event was completed. Included events are those that occurred during the interruption period beginning with the state of the scenario before the start of the interruption (the last viewed state of the primary task by the operator). The ‘Elapsed Events Image Viewer’ tool consists of the Image Viewer window and the Image List window. When the human operator chooses a text from the
image list, the image corresponding to the text is displayed in the Image Viewer window. The Image Viewer contains 2 important features:

1. Zoom feature: Operators can zoom in/out of an image by right-clicking on the window. Upon right-click, a window displaying the different zoom levels opens. The operator can choose one zoom level to reset the image size on the viewer.

2. Picture Tracker: A small rectangular window on the right side of the Image Viewer is the picture tracker. This small window shows the compressed image of the image shown on the Image Viewer. The picture tracker has a rectangular transparent box which when moved over the picture tracker surface (by holding the left mouse button on the transparent box), shows on the Image Viewer that region of the map display selected using the transparent box.

Figure 8: Snapshot of Elapsed Event Image Viewer Tool with the Image List
When the operator resumes the primary task, certain information for which visual cues assist the operator in regaining awareness and hence control are:

- current fuel level of a UCAV and if any UCAV is in danger of running out of fuel (flashing fuel gauge indication),
- current health status of a UCAV and the number of weapons on it (digital numbers on the display panel),
- if there are any changes in the route of a UCAV, past and current route of each UCAV displayed as time-stamped images in the ‘Elapsed Events Image Viewer’,
- past and current position of each UCAV on the map display which is again displayed as images in the ‘Elapsed Events Image Viewer’,
- any new known or unknown targets that have popped-up are displayed on separate images viewable via the ‘Elapsed Events Image Viewer’,
- targets identified during this time are shown on the image display, and
- enemy targets and no-fly-zones that were evaded during the interrupted time are also shown on the image display

4.5.6 Visual display cues for solution exploration

Humans in an emergency situation, where decisions must be made quickly, are believed to perform mental simulation using their mental model of the scenario and current data collected from the situation. Most of the time, the operator must recall from memory the parameters for which data is collected. When the complexity of the scenario is high and when the entire scenario is dynamic in nature, changes happen quickly and uncertainty exists in the
huge set of information that the operator uses for mental simulation. It is difficult to maintain a robust mental model of the scenario.

In such cases, it is essential and beneficial to the operator, that all necessary information be provided visually as a part of the display interface. The display component shows to the operator how the situation evolved for the changes that they intend to make on the system.

In the current context of primary and secondary scenarios involving UAVs, the solution exploration display tool is specifically used for planning the UAV route in the secondary task scenario. The set of cues in this display assist the operator in determining an effective route for each UAV on the reconnaissance mission, where each UAV has to survey a set minimum number of targets before returning to base.

The display tool indicates to the operator, for every vehicle under their control, whether the combination of assigned targets, fuel remaining on the vehicle and specified loiter time at each assigned target, allow the UAVs to reach their base before running out of fuel. The display tool shows the amount of fuel remaining onboard the vehicle when it reaches each of its assigned surveillance targets. Additionally, the current distance between the UAV and its home base is displayed along with the distance that can be traveled by the UAV with the fuel onboard. This gives a clear indication to the operator if the UAV route is good or must be changed.
If an UAV meets the requirements of number of targets to be visited, and would also reach the base successfully with the planned route, the background color of that UAV’s name on the display is changed to green color. If the UAV does not satisfy the requirement of number of targets to be covered in its route, then the background color of that UAV’s name is colored yellow. If the UAV on its planned route will run out of fuel before reaching the base, then the background color of that particular UAV name is changed to red color. Figure 18 displays the solution explorer (route analyzer) as a part of the secondary dissimilar user interface display.
4.5.7 Alert technique to notify about the secondary task

Both a visual and an audio-visual alert are included in the primary task scenario interface. The alert window activates when there is another task scenario (secondary task) that requires the operator attention. The alerts designed in this research are

a) a visual alert - a flashing red color block

b) an audio-visual alert - a flashing red color block with an audio signal in the form of beeps.

The alert window is on the bottom right hand of the map display (when the operator is facing the map).

4.5.8 Visual cues for Mode Awareness

In this dual-task scenario design, the human operator would come across two different system modes: a) Manual and b) Semi-automatic. When the human operator is monitoring and controlling one scenario (primary task or secondary task), that task scenario is in ‘Manual’ mode. The operator can control all behaviors of the UAV or UCAV such as identifying a target, identifying the type of enemy target, destroying an enemy target with the correct weapon, evading a detected no-fly-zone, returning to the base when the fuel is low, loiter time at a target location, and UAV altitude at a target location. When the operator is not monitoring an UAV or UCAV, the system is in ‘Semi-automatic’ mode. The UAV / UCAV behaviors are controlled by the system. In the semi-automatic mode, the UAV performs certain actions without operator request. Some of these actions include identifying a target, evading a target if it is an enemy, evading a detected no-fly-zone, and different fixed loiter times for low priority, medium priority, and high priority targets.
During the supervisory control of the dual-task scenario, when the operator is abruptly taken to the secondary task, the primary task is automatically set to ‘Semi-automatic’ mode. Initially, the secondary task scenario is in ‘semi-automatic’ mode. The human operator must change the mode to ‘manual’ so that they can control the UAV behavior. At the time of switching back to the primary task, the operator must set the secondary task mode to ‘semi-automatic’ and upon return to the primary task, in order to resume control over the UCAVs, the operator must set the mode to ‘manual’.

**Figure 10:** Snapshot of system mode control design on the baseline user interface

In the research study, the system mode can be controlled via buttons embedded on the top center of the display screen. The buttons are labeled ‘SEMI-AUTO’ and ‘MANUAL’, representing the ‘semi-automatic’ mode and the ‘manual’ mode respectively. In the baseline interface, the current system mode is visually represented by disabling the button that controls one particular state as show in Figure 10. The current system state is ‘manual’ and hence the button labeled ‘MANUAL’ is disabled. When the operator switches the mode to ‘semi-automatic’, the ‘SEMI-AUTO’ button will be disabled and the ‘MANUAL’ button will be enabled.

**Figure 11:** Snapshot of system mode control design on the advanced user interface

In the advanced user interface design, color-coding is used in addition to disabling the button, to visually depict the current system mode. Figure 11 indicates that the system is currently on ‘manual’ mode. Hence, the ‘MANUAL’ button is disabled and the button
background color is set to yellow. When the operator changes the system mode to ‘semi-automatic’, the ‘SEMI-AUTO’ button is disabled and the button background color is set to yellow, while the ‘MANUAL’ button is reset to the enabled state and the background color is reset to the default system color, which is dark gray.

4.6 Summary

This chapter detailed the research study – the three stages in the dissertation research, the research questions in the field of dual-task scenarios the study addresses, the application domains utilized to answer to the research questions, and the user interface components designed for the research.
5. EXPERIMENT 1: EFFECT OF INTERRUPTIONS ON TEAMS

This experiment examines the effect of interruptions in complex time-critical scenarios and conjectures visualization methods that can be developed to assist the human in performing in multi-task situations.

5.1 Introduction

The first experiment was conducted to examine team performance in an interruption-laden environment, examine whether information sharing about a current situation via a situation awareness calibration strategy helps in enhancing team performance, and whether textual communication is sufficient for effective team performance? Another issue studied was whether interruptions affect trust and coordination between members in a team.

5.2 Scenario Description

The scenario involved three member teams in logistics operations. Each team was composed of a commander and two soldiers called (Alpha soldier and Bravo soldier). The scenario was developed in the Virtual BattleSpace 1 (VBS1) game, on an existing imaginary island called Al-Almar. Different resources were placed at different locations on the island. Resources included soldiers of different types and materials, vehicles such as humvees, trucks, tankers, that the soldiers had to count and sometimes use to navigate from one location to another. Enemies were strategically placed in the scenario and their location was
unknown until the soldiers were within enemy firing range. Participants were informed that they were part of a logistics team required to report a count of resources at different locations in the scenario location. In the scenario, the Alpha and Bravo soldiers were required to go to seven different locations on the island and perform thirteen missions. The first mission for both Alpha and Bravo started from the Airport location in the scenario. Figure 12 shows a snapshot of the online map that was available to all three team members. From the game screen, the participants could toggle to an online map by using a keyboard shortcut, ‘M’. In the mission exercise, the soldiers were not supposed to shoot at the enemy unless necessary. The soldiers must first try to evade the enemies and perform their assigned tasks.

In this scenario, the primary task for the soldiers was the navigation of the vehicle to an assigned location and find and report the resource level in that location. A secondary task for the soldiers included both known and unknown interruptions.

The known interruptions were:

- Reading a new message on the chat tool whenever it appeared, irrespective of whether the message was relevant or irrelevant to their current primary task;
- Acknowledge receipt of a mission order from the commander;
- Toggling from the scenario screen to the online map to understand their current location; and
- SA calibration performed every ten minutes by the experimental group commander.

The unknown interruptions were:

- Enemy attack causing the soldier to find another route;
o Enemy attacking and the soldier’s vehicle destroyed, leading to mission failure for the soldier;

o Vehicle crashing into some object on the island and hence unable to continue use at which point the soldier must find another vehicle to perform the assigned missions; and

o Another team member asking you for help during your mission

The SA calibration procedure involves:

a. Commander states the current mission goals.

b. Commander asks the following questions to each soldier:
   - What is your current status?
   - Is your mission clear?
   - Have you seen any indication of enemy activity?

c. Each soldier provides the commander information regarding anything encountered that might affect the mission.

The commander’s primary task was to provide soldiers their mission orders via the chat window. This primary task included using the chat window to view soldiers’ responses on resource quantity at each of the soldier’s mission completion. The secondary task (which is a known interruption) for the commander was to fill the resource checklist with the count of various resources provided by the soldiers. The secondary unknown interruption task was the commander moving out of the Airport location and executing a mission order in place of one of the soldiers. For example, a soldier loses their vehicle and cannot find a spare vehicle to complete the mission. Another example would be to fill in for an injured soldier. Figure 13
shows a snapshot of the scenario with the soldier and the chat dialogues (in cyan color) at the bottom of the scenario showing message exchanges between commander and bravo.

In the window, a message sent by a team member is received by all team members. The chat window has four lines with the top line fading after a few seconds.

**Figure 12**: Snapshot of online map used while performing the mission in the VBS1
5.3 Research questions and Hypotheses

The following summarize the three research questions and corresponding hypotheses for this experiment.

1. Despite interruptions, do the teams performing situation awareness calibration during their missions, successfully complete more missions than other teams?

Hypothesis 1 (null hypothesis): In an interruption-laden task scenario, there is no difference in the percentage of missions successfully completed between the teams performing situation awareness calibration and the teams not performing it.

Hypothesis 1 (alternate hypothesis): In an interruption-laden task scenario, the teams performing situation awareness calibration successfully completed a higher percentage of missions compared to the teams not performing it.
2. Despite interruptions, do teams performing situation awareness calibration during their missions, complete the missions in less time compared to the teams not performing the calibration?

Hypothesis 2 (null hypothesis): In an interruption-laden task scenario, there is no difference in time required to complete all missions between the teams performing situation awareness calibration and the teams not performing it.

Hypothesis 2 (alternate hypothesis): In an interruption-laden task scenario, the teams performing situation awareness calibration completed all missions much more quickly than the teams not performing it.

3. Does performing situation awareness calibration in an interruption-laden task scenario, help in maintaining higher levels of trust between team members?

Hypothesis 3 (null hypothesis): There is no difference in trust among teams on teams performing situation awareness calibration and the teams not performing it, when there are interruptions in the scenario.

Hypothesis 3 (alternate hypothesis): When there are interruptions in the scenario, members in a team performing situation awareness calibration maintain higher levels of trust compared to members in a team not performing situation awareness calibration.

5.4 Method

The experimental design was a single factor between subjects design.

The independent variable was ‘Situation Awareness (SA) Calibration’ at two levels: ‘not performing SA calibration’ [Control group] and ‘performing SA calibration’ [Experimental group].
The dependent variables were

- Total time to complete all missions measured in minutes. It was expected that the missions could be completed within 1 hour.
- Percentage of missions completed successfully by the entire team, and
- Trust and confidence measurements on a scale of 1 to 7. Participants completed a questionnaire at the end of the study containing questions on trust and confidence in their team members (see Appendix A).

5.5 Participants

The participants in the research study were graduate and undergraduate students from Wright State University. Overall, 14 three member teams of participants were recruited for the study, 7 teams were in the experimental group while the remaining 7 teams were in the control group. All participants were experienced with first-person shooting video games. For any team, the participant selected for playing the Bravo soldier had an ‘expert’ level of gaming experience while participants playing Alpha and Commander were selected with at least ‘intermediate’ level of gaming experience. A screening survey was used to identify the potential participants. An ‘expert’ gamer is one who has played several first person shooting games for more than 5 years and continues to frequently plays such games. An ‘intermediate’ level of gaming experience is where the person has good video gaming experience but plays first person shooting games only occasionally. Expert gamers were chosen to play the Bravo soldier because it was expected that the Bravo soldier, in addition to performing their assigned missions, if there is a problem to Alpha or Commander, will be able to help the team complete the missions successfully.
5.6 Apparatus

A video game, Virtual BattleSpace 1 (VBS1) was used in the study. VBS1 is designed and sold by Bohemia Interactive Studio, an Australian based company. The mission scenario was built using this software. The software was installed on three computers with Windows XP Professional operating system and running on a 2.79 GHz personal computing system with 1 GB memory. A 17-inch LCD monitor was used to display the interface, with a mouse and keyboard used as the input devices. The participants were seated in an adjustable office chair, with the mouse and keyboard placed at a comfortable position as determined by each participant. The experiment was conducted in an office-like environment with the three computers placed at different corners in the room so that the participants are seated away from each other and hence unable to look at each other and talk to each other or give hand signals.

5.7 Procedure

The three participants on each team were seated in different corners of the same room, in front of computers. Once the participants signed the consent form, a document was handed out to all participants that informed them about the basic ‘gameplay instructions’ for interacting with VBS1 gaming software. They were asked to read through the information and wait for instructions. They were then asked to turn on the monitor and perform training using the provided ‘gameplay instructions’. The training was completed when each participant drove one vehicle to the ‘Airport’ location in the scenario and got their soldier out of the vehicle.
Participants in the experimental group received the Situation Awareness (SA) Calibration information sheet. The SA calibration was performed as a means to share information among team members and hence have a feeling of shared awareness about the complete environment. Information sharing was accomplished via the chat window. The commander on the team initiated the SA calibration at ten minute time intervals. At these times, the commander would communicate with each soldier, have them state their goals, ask whether they were clear about the current mission task, the situation around them in the scenario and whether they observed any enemy activity on their route which might delay or disrupt the ongoing mission(s).

In the experimental group, before the missions were started, the Bravo soldier was tasked to initiate a conversation with the other team members using the chat window. This process was called as the “Break-the-Ice” exercise (Wainfan and Davis, 2000). The team members were asked to share general information about themselves and what they felt about the gaming software. The process was conducted so that the team members could get to know each other to some extent. The control groups were not asked to perform the SA Calibration or the Break-the-Ice Exercise.

After the initial training, each participant was given an information packet containing further instructions. The commander team member received a packet containing a Command Information Sheet, a sample mission order, and a resource checklist. The resource checklist was a table listing all types of resources in the scenario, the available intelligence data on each resource quantity, and a blank column requesting the actual count determined during the experiment. The commander was asked to read the instructions and begin the game when they were ready by typing the following line in the chat window, “I am
your new commander, I will be issuing you orders from now on”. The Alpha and Bravo soldiers were also given a packet containing the Information Sheet, a terrain map, and a reference sheet mapping different equipment and players in the game. Alpha and Bravo soldiers were told to watch their screens for further instructions sent via the chat window.

Once the commander signaled the beginning of missions via the chat window, the investigator delivered the mission orders to the commander at intervals throughout the scenario. Overall, thirteen mission orders were delivered to the commander in a time span of forty-eight minutes. Certain mission orders contained sub-tasks.

The commander assigned the mission tasks to the Alpha Soldier or the Bravo Soldier. The commander was instructed to send only one soldier on any mission. The soldiers performed their assigned missions by navigating their vehicle to a specific location and reporting back to the commander the count of a specific resource mentioned in the mission order. If the count provided to the commander was different than the intelligence-based count, the commander had to determine which count to trust. After completing all the missions, the participants completed a survey on trust and were provided with a debrief of the study.

5.8 Results

**Hypothesis 1 (null hypothesis):** In an interruption-laden task scenario, there is no difference in the percentage of missions successfully completed between the teams performing situation awareness calibration and the teams not performing it.
A t-test was conducted to determine if any statistical significant difference exists between the two groups with respect to percentage of missions successfully completed. It was found that there was no statistical significance ($t_0 = -0.419, p\text{-value} = 0.34 > 0.05$) between the two groups.

Figure 14 depicts that both groups completed nearly 75% or more of the missions successfully.

**Figure 14**: Graph depicting the percentage of missions completed successfully by the groups.

**Hypothesis 2 (null hypothesis)**: In an interruption-laden task scenario, there is no difference in time required to complete all missions between the teams performing situation awareness calibration and the teams not performing it.
A t-test was conducted to determine whether statistical significant difference existed between the two groups’ mission completion time. It was found that there was no statistical significance ($t_0 = -0.962$, p-value = 0.177 > 0.05) between the two groups.

The teams were expected to complete the mission within 1 hour. Of the fourteen teams, only two control group teams and one experimental group team completed the missions within 1 hour. However, the two control group teams that completed all tasks within 1 hour, the percentage of missions completed was only 61.540 % and 76.920 % respectively.

![Comparison of mean total mission time between control and experimental groups](image)

**Figure 15**: Graph depicting the mean time taken by the groups to complete all missions

Figure 15 displays the mean time taken by each group to complete the assigned missions. The slightly higher mean mission completion time of the experimental group could be because of performing SA calibration as an additional task for the teams.

We expected a much longer missions completion time by the experimental group because of the requirement to perform SA calibration. However, the SA calibration was not
performed as regularly as requested; only one experimental group performed it perfectly every 10 minutes.

**Hypothesis 3 (null hypothesis):** There is no difference in trust among team members on teams performing situation awareness calibration and the teams not performing it, when there are interruptions in the scenario.

A survey (see Appendix A) was handed out to the participants at the end of the study. It consisted of seven questions pertaining to trust and confidence of their team members. Each question was rated on a scale of 1 to 7, 1 being ‘strongly disagree’ and 7 being ‘strongly agree’.

For each question, the mean response value was compared between the control group and the experimental group.

**Table 5: Mean responses to survey questions by participants**

<table>
<thead>
<tr>
<th>Survey Question</th>
<th>Control group mean response</th>
<th>Experimental group mean response</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Overall, the people on my team are very trustworthy</td>
<td>5.30</td>
<td>5.20</td>
</tr>
<tr>
<td>2. There is a noticeable lack of confidence among the people on my team</td>
<td>5.70</td>
<td>5.05</td>
</tr>
<tr>
<td>3. We have confidence in one another on this team</td>
<td>4.90</td>
<td>5.35</td>
</tr>
<tr>
<td>4. I can trust members of this team</td>
<td>4.65</td>
<td>4.15</td>
</tr>
<tr>
<td>5. There are times when members of this cannot be trusted</td>
<td>1.00</td>
<td>0.90</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>6. I have confidence in the members of this team</td>
<td>4.10</td>
<td>4.30</td>
</tr>
<tr>
<td>7. I feel I can trust the members of this team completely</td>
<td>5.05</td>
<td>4.75</td>
</tr>
</tbody>
</table>

Based on the data in Table 5, there does not appear to be any difference in mean response of each group with respect to trust level and confidence among team members. Participants in both groups maintained an above average level of trust of their team members. Based on means values of trust and confidence (Table 5), the control group members trusted each other slightly more than the experimental group team members. The control group team members showed relatively less confidence (questions 2 and 6 on Table 5) on each other. The experiment showed that performing the SA calibration did not lead to a higher level of trust among team members. Irrespective of whether they were performing the SA calibration or not, the commander trusted the soldiers in providing the accurate count of resources and the soldiers trusted each other in helping out in case of problems such as vehicle damage.

5.9 Discussion

Overall, in certain teams, some missions were not performed by the soldiers. The commanders forgot to keep track of such missions and request the soldiers perform them. In most cases, such missions involved the movement of a vehicle from one location to another or the transportation of soldiers from one location to another. Such instances occurred in both groups. One reason for such occurrences was partly because the commanders issued orders that consisted of sub-missions (see Appendix A). The soldiers tended to remember just the first part of the mission. By the time the soldier completed the first part of the mission, the
commander sometimes issued a completely new mission to the soldier. In such cases, the soldiers began to work on the new mission and did not go back to the earlier sub-missions. Their reason for neglecting the mission was not known; it may have been related to short term memory loss or the belief that the commander had scrapped the remaining part of that mission.

Out of the thirteen missions, there was one top priority mission that was skipped by one of the control groups. The reason was similar; the commander issued two missions to the same soldier in immediate succession and the former was forgotten. The soldier attended to the second mission first and did not perform the top priority mission. It was expected that the commander would remind the soldier about the top priority mission because the commander required ‘the count of number of survivors’ for the resource checklist. However, the commander neither requested nor filled the information with respect to the count and seemed to have forgotten completely about the mission. This could be a case of short term memory loss since, on the resource checklist (see Appendix A), the ‘number of survivors’ was not printed and the commander had to hand write that information with respect to that top priority mission. Such instances of short term memory loss could be prevented and information regarding status of missions could be enhanced with a visual aiding tool embedded in the system.

The overall longer mission times were due to the interruptions such as a vehicle crashing and an enemy attack as well as instances where the soldiers requested the commander re-state the mission because either the soldiers had forgotten details about the mission or the mission order information had vanished from the chat window before it could be completely read and understood by the soldier. Longer mission times also occurred when
the commander requested the soldiers repeatedly search the same location because the count of resources was different than the intelligence-based predicted data.

There was a lack of communication with respect to the quick update of critical information, especially from the soldiers to the commander. In situations when there was an enemy attack or the vehicle had crashed, the soldiers took a long time to convey the information to the commander who by then believed that the soldier had completed their earlier mission, and so issued the soldier another new mission order. Under such circumstances, the soldier did not inform the commander about the incomplete mission. These incomplete missions were unnoticed until near the end of all the missions. Realizing a gap in information due to the incomplete mission, the commander re-tasked the incomplete mission. These incomplete missions took the longest time for the soldiers to complete due to being out of position on the island. Had the commander known earlier about the incomplete mission, the commander could have re-tasked the mission to a soldier in better position in the island. This action could have cut down the overall mission completion time. One such informative means could be a visual aiding tool such as a mission update window.

A system shortcoming was the chat tool, the only tool for team communication. The chat tool window only displays four lines of text at a time and the messages quickly fade away. There is no scrolling option allowing the soldiers to review prior chat dialog (and previous mission assignments). The soldiers requested the commander repeat the mission order on occasions when they required clarification.

Commander’s also faced a problem with the chat tool’s information display limitation. The commanders sometimes missed the resource count information provided by
the soldiers. They had to then request the soldiers reconvey the information. Both unconveyed and missed information caused mission completion problems.

The lack of difference in trust levels could be related to scenario interruptions. From the subjective responses, the commander’s view of trust was related to

- Speed of completing missions,
- Efficiency of mission performance (in most cases), and
- Quickness of response to commander’s requests.

The speed and efficiency of mission performance was affected by interruptions. Soldier interruptions were not known to the commander unless the soldiers immediately informed the commander, which almost never happened. Although not evident from the subjective scale measurements, trust seemed to have been affected by interruptions in the scenario.

All these shortcomings – problems in completing missions quickly, problems in conveying critical information, problems in receiving critical information, and trust issues could be overcome by a system technique to visually display at-a-glance the information and the updates to all team members. With respect to this scenario, a status-at-a-glance display of the set of missions issued and the missions completed could keep the soldiers and commanders on track. The status-at-a-glance display could be populated with information obtained intelligently from the chat dialogues. For example, when the commander issues an order to a soldier, the mission order could be displayed in the at-a-glance windows of the commander and the specific soldier. When the soldier completes the assigned missions and informs the commander regarding each mission completion with the count (if the mission requires a count), then that particular mission could be updated with more information.
delivered by the soldier and grayed-out on the at-a-glance display. A ‘graying-out’ of information could symbolize mission completion. The mission information would not be removed from the at-a-glance display and each new assigned mission could be added on the bottom of the list of missions. Such a display could convey to the user (commander or soldier) at any time:

- total number of missions assigned during the session,
- number of missions successfully completed,
- information regarding completed missions,
- current mission order,
- a comprehensive summary of each soldier’s assigned missions, and
- a comprehensive summary of all missions assigned by the commander to all soldiers and mission completion status.

Finally, removing the map display interruption could improve the team performance and shorten the time to complete all missions. In this case, the map display could be shown as a small display in the right bottom portion of main display screen (superimposed on the main display screen). It is generally preferable to provide all visual assistance for a scenario on one display screen rather than having multiple screens of information for the same scenario with only one screen viewable at any given time.
6. EXPERIMENT 2: VISUAL CUES – OPERATOR PERFORMANCE & INTERRUPTION RECOVERY

Overall, this research study focuses on designing and developing visualization methods to assist the human operator in countering the effect of interruptions in complex dynamic time-critical multi-task scenarios and hence perform tasks rapidly and effectively.

6.1 Introduction

Experiment 2 examines whether a single operator, when provided with information via different visual tools, can simultaneously monitor and control two task scenarios with relatively higher task performance efficiency and greater situation awareness than when monitoring and controlling the scenario with little visual information assistance.

In this experiment, one set of participants have a user interface with basic visual tools such as a message log listing events that have occurred and a properties window displaying all information about the object being controlled by the operator. Another set of participants have an advanced user interface with tools such as a status-at-a-glance display and message log window and an interruption recovery tool – Elapsed Events- Image Viewer that consists of an image viewing panel and a list box populated with names of saved image. All images are time-stamped. Since each image depicts an event, the image name contains the event time, the name of the entity involved in the event, and the activity performed by the entity.
6.2 Scenario Description

6.2.1 Primary task scenario

The primary task scenario involves UCAVs (Unmanned Combat Aerial Vehicles) applied to target identification and destruction. The modeled UCAVs are semi-autonomous with the human operators or controllers in charge of monitoring and controlling the vehicles; the operators perform supervisory control on the UCAVs.

The scenario is the monitoring and control of 2 or 4 UCAVs flying on a pre-assigned route covering certain waypoints or locations. All UCAVs are equipped with sensors and weapon systems. The UCAV weapon system is classified as a short-range missile, medium-range missile, or long-range missile. When an enemy target is within firing range, the operator has to choose the proper weapon and when to give the firing order to fire the weapon on the enemy target.

The scenario is defined by targets that may need to be destroyed by the UCAVs. The targets are classified as known and unknown targets. The known targets are either friends or enemies. The unknown targets are ‘Pending’ targets (targets whose identity has to be established), ‘Suspect’ targets (targets whose identity is currently ‘might be enemy’ and the identity has to be firmly established), and ‘Assumed Friend’ targets (targets that are assumed friendly and their identity has to be firmly established). Enemy target categories vary and include SAM sites, tankers, and fighter aircraft.

When the UCAVs are near the targets, the sensors on the vehicles are used to help identify the target as a friend or foe. The scenario also contains no-fly zones and emergent (pop-up) targets. No-fly zones are regions over which the UCAVs are prohibited from flying.
If the UCAVs fly over these regions, they can be fired upon and destroyed or may have airspace conflict with other friendly aircraft in the area.

Emergent targets can pop-up anywhere, either close to the pre-assigned path of one of the UCAVs or far away from any of the current routes of the UCAVs. The operator may need to re-route the UCAV from its assigned path to identify the emergent targets. The assignment of an UCAV to a known enemy or unknown target depends on current parameters of the UCAV: the fuel remaining on the vehicle, proximity of the UCAV to the unidentified target in this context, number of other unidentified targets already assigned to the UCAV, proximity to the other targets assigned to the UCAV, no-fly zones that are in the UCAV path, and total number of UCAVs that are being controlled by the operator. If one, or a few, of the known enemy or unknown targets are in the far zone of the controlling terrain region, the operator (controller) must decide whether that particular target can be identified before any of the UCAVs return to base or should the target be ignored.

In the case of unknown targets, the UCAV will perform Identification of Friend or Foe (IFF) operation to differentiate between friend (civilian) and enemy (military) vehicle. After identification of the target, and if the target type is ‘Enemy’, then the category of this enemy target is identified. UCAV sensors are deployed again to identify the enemy target category. Finally, after determining the enemy target category, the operator selects the appropriate weapon type to deploy against the ‘Enemy’ target.

6.2.2 Secondary task scenario

The secondary task scenario is also from the domain of Unmanned Aerial Vehicles (UAVs). In this scenario, the UAVs are involved in reconnaissance missions. At any time,
the operator is monitoring and controlling 2 or 4 UAVs that are flying to specific destinations (targets) and collecting available information. These destinations are either enemy targets or neutral targets. Based on the severity of the enemy target region, targets are classified as low priority targets, medium priority targets, or high priority targets. The operator always has up-to-date information about the entire scenario, the status of all the UAVs, and the number of targets to visit in the region. The UAVs are assigned to a target, using the information that is available to the operator.

In this reconnaissance mission activity, information collection at each target is visually depicted as a UAV loitering over the target for an operator-assigned period of time. The loiter time varies based on the severity level of the target. When the UAV is loitering over the target, it retrieves information from the target and sends the information to the operator. The complexity of the mission scenario also differs with respect to the number of targets in the map region - high target density and low target density. In the high target density scenario, the operator has 4 UAVs for about 70 targets and in the low target density scenario the operator has only 2 UAVs in their control, for about 40 targets.

At the start of the mission, there are a few targets on the UAVs pre-assigned route. Once in the scenario, targets will pop-up in the region and be displayed on the map. All the targets will pop-up at about the same time. The number of targets appearing on the map region vary between 40 (low density situation) or 70 (high density situation). The number of targets appearing on the screen relates to the number of UAVs in the control of the supervisor. Once the targets have appeared, the operator must re-route the UAVs so that each UAV visits at least 5 high priority targets, 3 medium priority targets, and 4 low priority targets in its route for a low target density situation and at least 6 high priority targets, 5
medium priority targets, and 4 low priority targets in its route for a high target density situation. The operators also have the capability to change loiter times of the UAVs at each target location. The loiter times vary between few time units (3-6 seconds) on a low priority target to 7-10 seconds on a medium priority target to relatively more time (10 -13 seconds) on a high priority target. The loiter time is higher for high priority targets than low priority targets because we assume the high priority targets are regions where the UAVs might find more enemy information. When the UAV approaches the assigned target, the operator must change the UAV loiter time based on the type of target being approached. The UAV will also reduce in altitude and the speed. The altitude and speed changes conceptually signify that the UAV is conducting surveillance on the target. If the loiter time and altitude of the UAV does not meet the requirements for a surveillance condition, the UAV cannot collect information on the target to send back to the operator.

6.3 Task Models

An interface designer must completely define all the tasks that are performed by the human operator to design an effective interface. In this research, task models for the primary and secondary task scenarios were created. The task models are based on the OFM model approach (Narayanan et al., 2000). Figure 16 and Figure 17 depict the OFM decomposition for the primary task scenario and the secondary task scenario, respectively.
Figure 16: Task model for primary task scenario based on the OFM
Each node in the OFM models represents the task performed by the human operator. For example, in Figure 9, if an unknown target is present somewhere on the map region away from the current route of the UCAV, the operator adds or changes waypoints of the particular UCAV so that it is routed towards the unidentified target. Once the unknown target is reached, it is either a ‘pending’ target or ‘suspect’ target or ‘assumed friend’ target. Using sensors on the UCAV, the target is identified. If the target is an enemy, then the enemy type is determined and a related weapon type is deployed to destroy the target.

**Figure 17:** Task model for secondary task scenario based on the OFM
6.4 Research questions and Hypotheses

1. In the primary task, does the status-at-a-glance display and message log assist the human operator in maintaining situation awareness and perform tasks?

**Hypothesis 1 (null hypothesis):** There is no difference on the availability or unavailability of status-at-a-glance display and message logs on the operator ability to quickly gather and maintain situation awareness and perform tasks efficiently.

**Hypothesis 1 (alternate hypothesis):** The availability of status-at-a-glance display and message logs assists the operator to quickly gather situation awareness and perform tasks efficiently.

2. Does the status-at-a-glance display in the secondary task scenario assist the operator in rapidly attaining situation awareness?

**Hypothesis 2 (null hypothesis):** In the secondary task, there is no difference in time taken by operator for situation assimilation with or without a status-at-a-glance display.

**Hypothesis 2 (alternate hypothesis):** In the secondary task, the status-at-a-glance display assists the operator in faster situation assimilation.

3. Do visual display cues for solution exploration events assist the human in effectively and quickly conducting planning tasks?

**Hypothesis 3 (null hypothesis):** There is no difference in operator performance with or without the assistance of the solution exploration tool.

**Hypothesis 3 (alternate hypothesis):** The operator performance is more superior using the solution exploration tool.

4. Does the advanced user interface assist the operator resume primary task quickly compared to the baseline interface?
a. Does the complexity of the secondary task affect the time taken to resume the primary task?

b. Does the similarity of the secondary task to the primary task affect the time taken to resume the primary task?

**Hypothesis 4 (null hypothesis):** There is no difference between baseline interface and advanced user interface with respect to the time taken to resume the primary task.

**Hypothesis 4 (alternate hypothesis):** The taken to resume the primary task is much shorter using the advanced user interface.

5. Does the advanced user interface assist the operator obtain change awareness quickly in the primary task compared to the baseline interface?

**Hypothesis 5 (null hypothesis):** There is no difference between baseline interface and advanced user interface with respect to time taken to obtain change awareness.

**Hypothesis 5 (alternate hypothesis):** There is no difference between baseline interface and advanced user interface with respect to time taken to obtain change awareness.

6. Is secondary task resumption comparatively faster when using the advanced user interface display compared to the baseline interface?

**Hypothesis 6 (null hypothesis):** There is no difference in secondary task resumption time while recovering SA using an advanced user interface or a baseline interface.

**Hypothesis 6 (alternate hypothesis):** The secondary task resumption time is much shorter using an advanced user interface.

7. Does the presence of advanced user interface tools significantly reduce the change awareness time in the secondary task compared to the baseline interface?
Hypothesis 7 (null hypothesis): There is no difference in change awareness time when resuming operations in the secondary task (similar or dissimilar task) using the baseline display or the advanced user interface display.

Hypothesis 7 (alternate hypothesis): The change awareness time is much shorter when resuming operations in the secondary task (similar or dissimilar task) using the advanced user interface display.

8. In a dynamic dual-task condition, does the advanced user interface display help the operator maintain a relatively lower mental workload compared to the baseline interface?

Hypothesis 8 (null hypothesis): There is no difference in the mental workload between operators using the baseline display and advanced user interface display.

Hypothesis 8 (alternate hypothesis): The operator mental workload is much lesser using the advanced user interface display.

6.5 Method

The experimental design is a 2 (cue condition) X 4 (tasks complexity) X 2 (tasks similarity) mixed factorial design with the cue condition a between subjects factor.

The independent variables in the design and their factor levels are:

- **Cue Condition (Between-subjects factor)**
  - Baseline user interface
  - Advanced user interface

- **Task Complexity: Number of UAVs in the scenario (Within-subjects factor)**
  - Simple primary task (2 UAVs) and simple secondary task (2 UAVs)
  - Complex primary task (4 UAVs) and simple secondary task (2 UAVs)
- Simple primary task (2 UAVs) and complex secondary task (4 UAVs)
- Complex primary task (4 UAVs) and complex secondary task (4 UAVs)

- Task Similarity
  - Similar primary and secondary tasks (both are SEAD missions)
  - Dissimilar primary and secondary tasks (primary task is SEAD mission and secondary task is reconnaissance mission)

The dependent variables in experiment 2 are:

1. Time taken to perform Situation Awareness perception (SA1) tasks in the primary task.
2. Time taken to perform Situation Awareness comprehension (SA2) tasks in the primary task.
3. Time taken to perform Situation Awareness perception (SA1) tasks in the secondary task scenario.
4. Time taken to perform Situation Awareness (SA2) comprehension tasks in the secondary task scenario.
5. Number of correct responses to Situation Awareness tasks in the primary task.
6. Number of correct responses to Situation Awareness tasks in the secondary task.
7. Time taken to plan a successful mission route (Course of Action planning time) in the secondary task.
9. Number of targets left unassigned in the UAV route in the secondary task.
10. Primary task resumption time.
11. Secondary task resumption time.

12. Primary task - change awareness time (time to identify all significant changes in the primary task).

13. Secondary task - change awareness time (time to identify all significant changes in the secondary task).

14. Mental workload assessment – Using the NASA-TLX scale (Hart and Staveland, 1988), the mental workload and stress level reached by the operator during the study would be collected. Specific importance are given to the participants’ issues on the interface design and how these design issues contribute to increased mental workload (see Appendix B, Attachment 1).

During any given experimental trial, participants are asked Situation Awareness questions. Each SA question is displayed via a pop-up window. At the time of pop-up, all simulations are paused. For a SA question, the participant types the answer in the provided textbox and selects the ‘Submit’ button. Upon selecting the button, the pop-up window is closed and all simulation activities are resumed. Such SA questions are displayed every 20-45 seconds. The SA questions administered in the primary and secondary task scenarios are listed below:

*Primary Task Situation Awareness Questions:*

1. How many UAVs are there and what is the current UAV__ location?

2. Which UAV is currently consuming fuel at a faster rate?

3. Which UAV is moving faster?

4. Any health differences among UAVs?
5. What was the initial state of the last target detected by UAV__?

6. Until now, which UAV has more enemy targets in its route?

7. Is the total fuel capacity of all UAVs the same or different?

8. Where were all the UAVs on the map when you last performed the primary task?

9. Which UAV do you think must be attended first upon resumption?

10. What are the changes that you observe have happened during the interruption period?

11. What is the composition of identified enemy targets - count of SAMs / Tankers / Aircraft?

12. What was the final state of the target ___?

13. Provide complete terrain details.

14. Which UAV has completed the highest percentage of its route?

15. What were all the targets identified by UAV__?

16. How much ammunition (count) is left on each UAV?

17. The targets that were SAMs and Aircraft?

18. Which UAV route has been most threatening?

19. How many enemy targets are in the scenario until now and how many have been destroyed?

20. Target ___ - states transition details?

21. Will the UAVs make it to the base in their current routes?

22. What is the current UAV___ location?

23. What were all the targets identified by UAV___?

24. How many enemy targets are there in the UAV___ route?
Secondary Similar Task Situation Awareness Questions:

1. What is the current UAV__ location?
2. Which UAV is currently consuming fuel at a faster rate?
3. Which UAV is moving faster?
4. Any health differences among UAVs?
5. What was the initial state of the last target detected by UAV2?
6. How many enemy targets are there in the UAV__ route?
7. What is the composition of the enemy targets - count of SAMs / Tankers / Aircraft?
8. What was the final state of the target ___?
9. Where were all the UAVs on the map when you last performed the primary task?
10. Which UAV do you think must be attended first upon resumption?
11. What are the changes that you observe have happened during the interruption period?
12. Any health changes observed from before?
13. Which UAV route has been most threatening?
14. Provide complete terrain details.
15. Which UAV has completed highest percentage of its route?
16. How much ammunition (count) is left on each UAV?

Secondary Dissimilar Task Situation Awareness Questions:

1. Describe the secondary task scenario as viewed on the map?
2. Is there any fuel related difference between the UAVs? Specify.
3. Which UAV must have a shorter route while still covering the required amount of target locations?

4. Is there a difference in speed between the UAVs?

5. Where is the concentration of high priority targets?

6. Where are the UAVs currently on the map?

7. Currently, how many targets have been assigned to UAV__ and what is the composition?

8. Are there any health changes on the monitored UAVs?

9. How many targets have not yet been assigned to any UAV?

10. Which UAVs route plan must be completed

11. Write the position of each UAV just before switching to primary task?

12. What are the changes that you observe have happened during the interruption period?

13. Will the assigned route to UAVs remain or change due to some factors? Specify.

14. How many targets have been assigned to UAV__? Composition? Is it more or less than the other UAV count?

15. How many targets have been left out in the route? If any, why?

16. Which UAV has completed highest percentage of its route?

17. Are you confident that all UAVs following the assigned route, will reach the base safely?

6.6 Stimuli

The following set of screen snapshots depict what is shown to the participant during the study. Certain screens are specific to the ‘baseline interface’ group while others are specific to the ‘advanced user interface’ group.
Figure 18 shows a snapshot of the screen displayed to the participant at the beginning of an experimental trial. After reading the message contained in the two text boxes, the experimenter inputs the ‘subject no.’, and selects the primary and secondary task scenario for a given trial and selects the ‘Next’ button.

![Figure 18: Welcome screen displayed at the beginning of each experimental trial](image)

Figure 19 shows the first screen presented to the participant in the ‘baseline interface’ group. The interface has a map display, a property window by the right of the map display, a textual event history list and a fuel indicator panel. Selecting a UAV from the combo box gives the participant control over the UAV on the map display and shows that particular UAV attributes in the property window.
Figure 19: Baseline primary task UAV user interface with event history list and fuel indicators

Figure 20 again shows the primary task ‘baseline interface’. It shows a panel below the property window. When the UAV identifies a target as requested by the user by pressing the button ‘ID Target’, and if the target happens to be an ‘Enemy’ target, the panel below the property window is enabled. The user can click on ‘ID Enemy Type’ on the panel, to display the Enemy Type, and based on that information, the user selects one of the available missile types and clicks ‘Fire’ button on the user interface to destroy the target.
Figure 20: Baseline primary task UAV user interface with identification of enemy type and attack panel

Figure 21 displays the secondary task ‘baseline interface’ screen. As the map shows, each UAV is routed to a waypoint. The user must route the UAVs to the targets on the map and finally return the vehicle to the base (starting location). Other than the map, the user interface displays the UAV property window, the fuel indicators, and the panel displaying each UAV’s current altitude and loiter time.
Figure 21: Baseline secondary task user interface for UAV on reconnaissance mission

When the user returns to the primary task, they will see the same screen layout (as shown in Figure 22) as before leaving to the secondary task. During the time the user performs the secondary task, in the primary task the UAVs continue moving on their pre-assigned path, evading NFZs and evading enemy targets on their route. The events that occurred while attending to the secondary task listed in the textual event history list.

After the user returns to the primary task, the control is set to ‘Manual’ so that the user has control over the UAVs.
Figure 22: Baseline primary task UAV user interface upon task resumption

Users in the ‘advanced user interface’ group see a screen similar to the snapshot depicted in Figure 23 during their primary task. In this display mode, the user is provided a status-at-a-glance information panel, or ‘Summary Details’ panel, and the color-coded textual event history list. The steps for task execution on the map display are similar to the ‘baseline interface’.
Figure 23: Primary task scenario UAV user interface with status-at-a-glance display and color-coded textual event history

Figure 24 displays the primary task ‘advanced user interface’ with the panel for identifying the exact enemy type and hence destruction of that target with the correct missile.
Figure 24: Primary task scenario UAV user interface with the enemy identification and attack panel, status-at-a-glance display and color-coded textual event history

While performing the primary task, the user is taken abruptly to the secondary task. Figure 25 depicts the screen in the ‘advanced user interface’. Compared to the ‘baseline interface’, this screen displays the status-at-a-glance display (‘Summary Details’ window) and the Route Analysis tool. The Route Analysis tool helps the user create a ‘mission successful’ route for the UAVs in the scenario.
Figure 25: Secondary task scenario UAV user interface with status-at-a-glance display panel and route analysis panel

After routing the UAVs in the secondary task, the user returns to the primary task scenario and a display as in Figure 26 is seen. Users are provided an ‘Elapsed Events-Images Viewer’ tool. With this tool, the user sees a pictorial status of the scenario events that occurred while the user was performing the secondary task.
Figure 26: UAV user interface on primary task resumption with video replay panel, visual event trace request panel, other display panels

6.7 Participants

The participants in the research study were graduate and undergraduate students at Wright State University. All were familiar with Windows-based applications and familiarity in operating a mouse and keyboard configuration.
6.8 Apparatus

The simulation is written in C#.net and runs on a 2.79 GHz personal computing system running Windows XP Professional with 1 GB memory. A 17-inch LCD monitor is used to display the interface, with a mouse and keyboard used as the input devices. The experiment is conducted in an office-like environment. The participants are seated in an adjustable office chair, and the mouse and keyboard is placed at a comfortable position as determined by each participant.

6.9 Procedure

Participants were asked to sign an informed consent form. They were handed the training material and a sheet describing the icon terminology in use during the experimental trials. During the training phase, the participants learn to perform tasks in both the search and destroy scenario and the reconnaissance scenario. The specific tasks learned include selecting a UCAV or UAV, identifying a target, destroying an enemy target, evading no-fly-zones, assigning a target to a UAV, removing an assigned target from a route, re-assigning a target to a different UAV route, reading the properties window in the baseline interface, reading the status-at-a-glance display in the advanced interface, using the elapsed events image viewer, and performing tasks in response to emergency situations such as the UAV low fuel condition. After training on each scenario, the participants were trained to perform the same tasks in a dual-task environment. The participants were made aware of the system control mode (‘semi-automatic’ or ‘manual’) and to how change the system control mode to ‘semi-automatic’ before switching to another task scenario. Upon completion of training, participants performed tasks in eight experimental trials.
Each experimental trial was fifteen minutes long and contained tasks in both the primary and secondary task scenarios. The fifteen minute experimental trial was divided into 5 segments as shown in Figure 27.

**Figure 27:** Activity time model for each experimental trial

During each trial, the participant was interrupted twice in both the primary task and secondary task. Each trial began with a participant performing the primary task, which is the UCAV on a search and destroy mission. After three minutes, the participant was abruptly taken to the secondary task to perform reconnaissance operations. After four minutes, they return to the primary. At the end of ten minutes into the trial, the participant was again switched to the secondary task for two and half minutes after which, the final phase of the fifteen minute trial was spent working on the primary task. The task switch time was varied around a one minute range per trial to avoid any learning effect associated with the task switch at the end of each timed segment shown in Figure 27.

During the experimental trial, Situation Awareness questions popped up on the screen. At such instances, the simulation (both primary and secondary tasks) was paused. Once the participant typed an answer into the textbox and selected the ‘Submit’ button, the simulation resumed.
At the end of each trial, a NASA-TLX questionnaire was completed. After completing the eight trials, the participants completed an user interface satisfaction questionnaire. Finally, the participant was debriefed regarding the purpose of the study.

6.10 Results

Participant performance during the experimental trials was analyzed using Analysis of Variance (ANOVA) on the dependent variables. A three-factor mixed design ANOVA model was constructed. In the model, the cue condition is a between-subjects factor while task complexity and task similarity are within-subjects factors. Post hoc analysis was conducted to capture significant factor levels. The alpha criterion was set to 0.05. SPSS Statistics Release 17.0.0 was used for the analysis.

**Hypothesis 1 (null hypothesis):** There is no difference on the availability or unavailability of status-at-a-glance display and message logs on the operator ability to maintain situation awareness quickly and perform tasks efficiently.

The dependent variables for analyzing the above stated hypothesis are:

- Time taken to perform Situation Awareness perception (SA1) tasks – ‘Primary SA1 time’
- Time taken to perform Situation Awareness comprehension (SA2) tasks – ‘Primary SA2 time’
- Percentage correct responses to Situation Awareness questions – ‘Primary correct SA’
Time taken to perform Situation Awareness perception (SA1) tasks – ‘Primary SA1 time’:

It was found that there was a significant three way interaction effect of cue condition, task complexity, and task similarity [F (3, 42) = 5.442, p-value = 0.009, variance = 153.313]. Planned comparison of means revealed that the advanced user interface helped in obtaining SA1 significantly quicker than the baseline interface under all levels of Task Complexity and under all levels of Task Similarity. The main effect of cue condition was significant at F (1, 14) = 693.295, p-value < 0.001, variance = 1610.016. Pairwise comparison for the main effect of Cue Condition corrected to a Bonferroni adjustment showed that there was as significant difference. Comparing the mean ‘Primary SA1 time’ between the two Cue Condition levels reveals that using the advanced user interface, the mean ‘Primary SA1 time’ was 19.391 seconds which was more than twice that of the baseline interface time of 39.453.

![Comparison of SA1 times - Primary Task](image)

**Figure 28**: Graph depicting the Primary SA1 task times for all levels of the experiment
The two-way interactions and the main effects were all significant indicating that the advanced user interface significantly improved the ability to maintain SA1. The two-way interaction of Task Similarity and Cue Condition was significant at $F (1, 14) = 6.677$, p-value = 0.022, variance = 98.00. The main effect of Task Similarity was significant at $F (1, 14) = 31.175$, p-value < 0.001, variance = 457.531. Figure 28 also shows that while performing the tasks with the advanced user interface, users performed SA1 tasks quicker when the secondary task was similar to the primary task.

_Time taken to perform Situation Awareness perception (SA2) tasks – ‘Primary SA2 time’:_

The three-way interaction was not significant. There was a significant two-way interaction between Task Complexity and Cue-condition at $F (3, 42) = 17.939$, p-value < 0.001, variance = 384.898. Planned comparison of means showed that for all factor level combinations, the SA2 tasks were performed faster using the advanced user interface display. Figure 29 shows the mean SA2 times for the four levels of Task Complexity. The main effects Task Complexity and Cue Condition were also significant at $F (3, 42) = 55.267$, p-value < 0.001, variance = 395.279 and $F (1, 14) = 400.069$, p-value < 0.001, variance = 1271.368, respectively.
**Figure 29**: Graph depicting the Primary SA2 times for different level of task complexity

*Percentage correct Situation Awareness answers – ‘Percent correct primary SA’*

The analysis based on the response variable, Percent correct primary SA showed that there were no significant interactions in the model. The main effect, Cue Condition was significant at F (1, 14) = 457.947, p-value < 0.001, variance = 20915.493. Pairwise comparison for the main effect of Cue Condition corrected to a Bonferroni adjustment showed that the percent correct primary SA using the advanced user interface was 95.95 % which was significantly greater than 70.384 % correct responses using the baseline user interface (Figure 30).
Figure 30: Graph depicting the percent correct responses to SA questions in primary task

**Hypothesis 2 (null hypothesis):** In the secondary task, there is no difference in time taken by operator for situation assimilation with or without a status-at-a-glance display.

The dependent variables for analyzing the above stated hypothesis are:

- Time taken to perform Situation Awareness perception (SA1) tasks in the secondary task scenario
- Time taken to perform Situation Awareness (SA2) comprehension tasks in the secondary task scenario
- Number of correct responses to Situation Awareness tasks in the secondary task

Since the secondary task was either similar or dissimilar to the primary task, the SA questions for the secondary task varied between similar and dissimilar task conditions. Hence, six dependent variables were measured – three variables for similar secondary task condition and three variables for dissimilar secondary task condition.
Similar secondary task condition:

The similar secondary task condition is a UCAV on search and destroy mission scenario.

Time taken to perform Situation Awareness perception (SA1) tasks in the similar secondary task scenario:

The two-way interaction between Task Complexity and Cue Condition was significant at $F (3, 42) = 17.745$, p-value $<0.001$, variance = 66.557. Planned mean comparison showed that for all four levels of Task Complexity, time taken to perform tasks to obtain SA1 was quicker with the advanced user interface (Figure 31). The main effects Cue Condition and Task Complexity were significant at $F (1, 14) = 664.315$, p-value $<0.001$, variance = 2956.641 and $F (3, 42) = 123.891$, p-value $< 0.001$, variance = 464.682 respectively. Participants performed the tasks faster with the advanced user interface (15.34 seconds) compared to 28.94 seconds with the baseline user interface.

![Comparison of Secondary Task SA1 Times](image)

**Figure 31:** Graph depicting the SA1 time when performing a secondary similar task
Time taken to perform Situation Awareness (SA2) comprehension tasks in secondary task scenario:

The two-way interaction between Task Complexity and cue condition was significant at $F(3, 42) = 25.632$, $p$-value <0.001, variance = 123.354. Planned mean comparison showed that for all four levels of Task Complexity, as shown in Figure 32, SA2 tasks were performed significantly faster with the advanced user interface. The main effect of Cue Condition was significant at $F(1, 14) = 351.752$, $p$-value <0.001, variance = 3451.563. Performing a pairwise comparison for Cue Condition, corrected using a Bonferroni adjustment showed that there was significant difference between the two levels. Using the baseline user interface, participants took 26.813 seconds to respond to a SA2 task while, using the advanced user interface, it took only 12.125 seconds to complete a SA2 task.

![Comparison of Similar Secondary Task SA2 Times](image)

**Figure 32:** Graph depicting the SA2 time when performing a secondary similar task
Number of correct responses to Situation Awareness tasks in the secondary task:

Statistical analyses revealed that the main effects, Task Complexity and Cue Condition were statistically significant with $F (3, 42) = 5.199$, p-value = 0.006, variance = 180.348 and $F (1, 14) = 250.697$, p-value < 0.001, variance = 13805.075 respectively. A pairwise comparison on Cue Condition using Bonferroni adjustment showed that the percentage correct responses to SA questions was significantly higher for the advanced user interface at 93.957% compared to 64.584 % with the baseline user interface.

Dissimilar secondary task condition:

The dissimilar secondary task condition, the secondary task scenario is a UAV on reconnaissance mission scenario.

Time taken to perform Situation Awareness perception (SA1) tasks in secondary task scenario:

Statistical analyses showed that the two-way interaction between Task Complexity and Cue Condition was significant at $F (3, 42) = 6.824$, p-value = 0.001, variance = 32.625. Planned mean comparison showed that for all four levels of Task Complexity, time taken to perform tasks to obtain SA1 was significantly quicker with the advanced user interface (Figure 33). The main effect of Cue Condition was significant at $F (1, 14) = 2351.759$, p-value <0.001, variance = 12210.250. Performing a pairwise comparison for Cue Condition, corrected using a Bonferroni adjustment showed that SA1 tasks were performed significantly faster using the advanced user interface at 15.219 seconds compared to 42.849 seconds with the baseline user interface.
Comparison of Secondary Dissimilar SA1 times

<table>
<thead>
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<th>Task complexity</th>
<th>Baseline</th>
<th>Advanced</th>
</tr>
</thead>
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<td>11.75</td>
</tr>
<tr>
<td>Complex-Simple</td>
<td>36.625</td>
<td>11.625</td>
</tr>
<tr>
<td>Simple-Complex</td>
<td>47.75</td>
<td>18.25</td>
</tr>
<tr>
<td>Complex-Complex</td>
<td>49.875</td>
<td>19.25</td>
</tr>
</tbody>
</table>

Figure 33: Graph depicting the SA1 time when performing a secondary dissimilar task

Time taken to perform Situation Awareness (SA2) comprehension tasks in secondary task scenario:

The two-way interaction between Task Complexity and cue condition was significant at $F (3, 42) = 12.694$, $p$-value $<0.001$, variance $= 50.557$. Planned mean comparison showed that for all four levels of Task Complexity, as shown in Figure 34, SA2 tasks were performed significantly faster with the advanced user interface. The main effect of Cue Condition was significant at $F (1, 14) = 748.709$, $p$-value $<0.001$, variance $= 4176.391$. The SA2 task was performed significantly faster using the advanced user interface at 10.281 seconds while it took 26.438 seconds to complete a task using the baseline user interface.
Comparison of Secondary Dissimilar SA2 times

Figure 34: Graph depicting the SA2 time when performing a secondary dissimilar task

Number of correct responses to Situation Awareness tasks in the secondary task:

Statistical analyses showed that the main effect, Cue Condition was statistically significant at $F (1, 14) = 404.618$, $p$-value $< 0.001$, variance $= 16616.821$. Pairwise comparison using Bonferroni adjustment on this main effect showed that the percentage correct responses to SA questions was significantly higher for advanced user interface at 94.531% compared to 62.305 % with the baseline user interface.
**Hypothesis 3 (null hypothesis):** There is no difference in operator performance with or without the assistance of the solution exploration tool.

The dependent variables for analyzing the above stated hypothesis are:

- Time taken to plan a successful mission route (Course of Action planning time) in the secondary task
- Mission success rate in the secondary task
- Number of targets left unassigned in the UAV route in the secondary task

This hypothesis applies to secondary dissimilar tasks only because the solution exploration tool is designed to assist the operator in designing successful routes for UAV on reconnaissance missions.

*Time taken to plan a successful mission route (Course of Action planning time) in the secondary task:*

Statistical analyses showed that the two-way interaction effect between Task Complexity and Cue Condition was statistically significant at $F (3, 42) = 3.433$, p-value = 0.048, variance = 6311.432. Planned comparison of means showed that for all four levels of task complexity, time taken to plan a route for the UAVs was quicker (Figure 35) with the advanced user interface (226.094 seconds) compared to the baseline interface (335 seconds).
**Figure 35:** Graph depicting the time taken in planning a course of action in a secondary dissimilar task

**Mission success rate in the secondary task:**

Statistical analyses showed that the two-way interaction effect between Task Complexity and Cue Condition was statistically significant at $F(3, 42) = 5.529$, $p$-value = 0.002, variance = 2656.250. Planned comparison of means showed that at higher levels of Task Complexity, mission success rate increased significantly when performing tasks with the advanced user interface at 99.129 %, compared to 60.156 % with the baseline user interface (Figure 36).
Figure 36: Graph depicting percentage success rate of planned missions in a secondary dissimilar task

Number of targets left unassigned in the UAV route in the secondary task:

Statistical analyses showed that the two-way interaction effect between Task Complexity and Cue Condition was statistically significant at \( F(3, 42) = 3.328, \text{p-value} = 0.033, \text{variance} = 11.266 \). Planned comparison of means showed that at all four levels of Task Complexity, the number of targets left unassigned was significantly less when performing the task using the advanced user interface (Figure 37). The main effect of Cue Condition was statistically significant at \( F(1, 14) = 713.040, \text{p-value} < 0.001, \text{variance} = 1590.016 \). A Bonferroni adjustment on this main effect showed that, using the advanced user interface, the number of targets left unassigned was significantly less at 3.250 targets compared to 13.219 targets with the baseline user interface.
**Figure 37**: Graph depicting the number of unassigned target in a secondary dissimilar task scenario

**Hypothesis 4 (null hypothesis)**: There is no difference between the baseline interface and advanced user interface with respect to time taken to resume primary task

Dependent variable: *Primary task resumption time:*

The three-way interaction effect between Task Similarity, Task Complexity, and Cue Condition was not significant. The two-way interaction between Task Complexity and Cue Condition was significant at F (3, 42) = 15.209, p-value < 0.001, variance = 243.948. Planned mean comparison showed that for two levels of Task Complexity, that is, when the tasks were simple, the advanced user interface assisted the participants to be significantly quick in task resumption. The main effect of Cue Condition was statistically significant at F (1, 14) = 988.597, p-value < 0.001, variance = 15708.781. Task resumption was quicker with
the advanced user interface at 30.234 seconds compared to 52.391 seconds with the baseline user interface (Figure 38).

**Figure 38:** Graph depicting the task resumption time in a primary task scenario

**Hypothesis 5 (null hypothesis):** There is no difference between the baseline interface and the advanced user interface with respect to time taken to obtain change awareness.

Dependent variable: *Time taken to gain change awareness:*

The two-way interaction between Task Similarity and Task Complexity was significant at F (3, 42) = 5.008, p-value = 0.007, variance = 229.938. Planned comparison of means showed that there was a significant difference at one level of Task Complexity, ‘Simple primary-Complex secondary’ scenario. The time taken to obtain change awareness was shorter with the advanced user interface. The main effect of Cue Condition was significant at F (1, 14) = 597.401, p-value < 0.001, variance = 29282.00. Pairwise
comparison using Bonferroni adjustment showed that there was a significant difference in change awareness time between the advanced and baseline user interfaces (Figure 39).

**Figure 39:** Graph depicting the time taken to gain change awareness in a primary task scenario

**Hypothesis 6 (null hypothesis):** There is no difference in secondary task resumption time while recovering SA using the advanced user interface or the baseline interface.

Dependent variable: *Secondary task resumption time:*

The three-way interaction effect between Task Similarity, Task Complexity, and Cue Condition was significant at $F (3, 42) = 11.165$, $p$-value $< 0.001$, variance $= 126.438$. Planned mean comparisons showed that for all levels of Task Complexity levels and Task Similarity, the task resumption was significantly quicker with the advanced user interface display (Figure 40). The main effect of Task Similarity was statistically significant at $F (1, 14) = 183.646$, $p$-value $< 0.001$, variance $= 2664.550$ meaning task resumption was quicker
when the secondary task was similar to the primary task at 36.500 seconds compared to 45.625 seconds when the tasks were dissimilar. The advanced user interface assisted in quicker task resumption at 24.563 seconds compared to 52.563 seconds with the baseline user interface.

![Comparison of Secondary Task Resumption Time](image)

**Figure 40:** Graph depicting the task resumption time in a secondary task scenario

**Hypothesis 7 (null hypothesis):** There is no difference in change awareness time when resuming operations in the secondary task (similar or dissimilar task) using the baseline display or the advanced user interface display.

Dependent variable: *Time taken to gain change awareness:*

The three-way interaction effect between Task Similarity, Task Complexity, and Cue Condition was significant at $F (3, 42) = 6.894$, $p$-value $= 0.002$, variance $= 157.510$. Planned comparison of means showed that for all levels of Task Complexity levels and Task Similarity, the time to gain change awareness was significantly quicker with the advanced
user interface display (Figure 41). Change awareness was significantly faster with the advanced user interface at 25.563 seconds compared to 59.750 seconds with the baseline user interface.

![Comparison of Time to gain Change Awareness](image)

**Figure 41:** Graph depicting the time taken to gain change awareness in a secondary task scenario

**Hypothesis 8 (null hypothesis):** There is no difference in the mental workload between operators using the baseline display and advanced user interface display.

Dependent variables: *Mental effort, temporal effort, and frustration level based on the NASA-TLX scale:*

**Frustration level:**

The two way interaction effect between Task Complexity and Cue Condition was significant at $F(3, 42) = 4.714$, $p$-value $= 0.009$, variance $= 1.375$. Planned comparison of means revealed that at all four levels of Task Complexity, frustration level was higher with
the baseline user interface reaching a peak of 4.813, (see Figure 42), when performing the ‘complex primary – complex secondary’ scenario. The main effect of Cue Condition was significant at \( F (1, 14) = 217.00, \) p-value < 0.001, variance = 120.125. A pairwise comparison using Bonferroni adjustment showed that, using the advanced user interface, the frustration level was significantly lesser at a value of 2.00 compared to 3.938 using the baseline user interface.

![Comparison of Frustration Level](image)

**Figure 42:** Graph depicting the frustration level experienced by operator in the dynamic dual-task scenario

**Mental effort level:**

The main effect, Task Complexity was significant at \( F (3, 42) = 28.741, \) p-value < 0.001, variance = 10.404. The Cue Condition main effect was significant at \( F (1, 14) = 277.761, \) p-value < 0.001, variance = 76.570. A planned comparison of means showed that the mental effort required with the baseline user interface was significantly high at 4.109 compared to 2.563 with the advanced user interface. The interaction effect of Cue Condition
and Task Similarity did not show any significant effect. However, comparison of means revealed significant differences, see Figure 43. The mental effort level was highest when the two tasks were dissimilar and the participant was using the baseline user interface.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{comparison_of_mental_effort.png}
\caption{Graph depicting the mental effort spent on performing tasks in the dynamic dual-task scenario}
\end{figure}

\textit{Temporal effect:}

There was significant three-way interaction effect between Task Similarity, Task Complexity, and Cue Condition at $F(3, 42) = 3.249$, p-value = 0.032, variance = 1.260. Planned comparison of means revealed that for the dissimilar task scenario, at all four levels of Task Complexity, there was significantly high temporal effort when performing the tasks using the baseline user interface. For similar task scenarios, the temporal efforts were significantly different for the first two levels of the Task Complexity (see Figure 44). Overall, the mental effort required using an advanced user interface was 2.609 which was
much lesser than the mental effort of 3.641 that was required using the baseline user interface.

![Comparison of Temporal Level Scale](image)

**Figure 44:** Graph depicting the temporal effort applied by the operators in performing tasks in the dynamic dual-task scenario

### 6.11 Discussion

In experiment 2, a user interface with new set of visualization tools was examined with respect to operator ability to maintain situation awareness, gain change awareness rapidly and resume the primary task upon return, ability to understand the secondary task rapidly upon task switch.

The visualization tools that were examined include:

1. Status-at-a-glance display designed to maintain or rapidly obtain situation awareness.

2. Solution explorer or Route Analyzer designed specifically for routing UAV for reconnaissance missions. It is a part of the secondary task user interface display.
3. Elapsed events image viewer tool designed to assist the human in rapidly resuming a task after some interruption.

*Status-at-a-glance display:*

Given the results, there is significant difference between the baseline and advanced user interface with respect to the time taken to respond to the SA questions. Participants using the advanced user interface performed the SA1 and SA2 tasks significantly quicker than the participants performing the same operations on the baseline interface. In addition, the percentage of correct SA responses was significantly higher when performing tasks with the advanced user interface. This indicates that the status-at-a-glance display assists the system users in quickly obtaining and maintaining accurate awareness of current and evolving situation in the task scenario.

Few participants complained regarding the difficulty reading text displayed on the panel. Given the small size display limitation in this effort, small-sized visual components were used due to space availability. Other than the fuel indicators on the status panel, all information on the interface panel was textual. While likely, it is not clear whether making the status-at-a-glance purely graphical will make the information easier to comprehend while assisting the users in maintaining high SA. There is also the problem that not all parameters are easily graphed. The main goal in the design used in this research was to present all critical parameters per vehicle on the display as shown in Figure 45.
Figure 45: Snapshot of the status-at-a-glance display

Overall, the designed status-at-a-glance display positively affected operator performance by helping them maintain an accurate awareness of the situation and also helping the operator quickly learn about a new task scenario (secondary task scenario) when switching to that task.
Solution explorer (Route Analyzer):

The route analyzer helps the operator design routes for UAVs on reconnaissance missions. A close look at the display is shown in Figure 46.

![Figure 46: Snapshot of the Solution Explorer (Route Analyzer)](image)

From the results obtained, this route analyzer assisted the operator in designing a course of action quicker compared to the baseline user interface and helped the operator determine whether the designed course of action would succeed. Coupled with information from the status-at-a-glance display regarding complete terrain details, the operators were quite successful in routing the UAVs to all targets in the scenario. Compared to performance with the baseline user interface, the presence of a solution explorer in a time-critical decision-making task has helped the operator in making quick and accurate decisions and helped in either maintaining SA or regaining SA when returning from an interruption.
**Elapsed Events Image Viewer Tool:**

The tool assists the operator in quickly gaining change awareness upon return to the primary task after an interruption. It helps operators know where the UAVs were previously located and in understanding events occurring during the interruption period.

**Figure 47:** Snapshot of the Elapsed Events Image Viewer Tool with the Image List

Two advantages with the tool are that:

1) The user can select any text in the image list window and the corresponding image is displayed on the image viewer as shown in Figure 47. The operator does not need to view all images sequentially but rather in any order they wish (or need).

2) Each text in the image list is time-stamped and is descriptive of the event. The operator thus might not need to view the image to understand what happened at a particular time in the task scenario. Several illustrations are shown in Figure 48 to show how the text is descriptive of the event.
Figure 48: Snapshots displaying different image list descriptions and the corresponding pictorial representation on the image viewer.

Each textual description consists of 3 parts: the time, the entity involved, and the action performed by the entity. For example, ‘693_UAV2_Detected_NFZ1’ states that at time 693, the entity UAV2, detected no-fly-zone NFZ1. Similarly, the description ‘716_UAV1_Wp4’ states that at time 716, the entity UAV1, reached waypoint Wp4 and the description ‘675_Target7_Popup’ states that at time 675, the target Target7, appeared on the map display.

Results from the study showed that the primary task resumption time and time taken to gain change awareness was quicker using the advanced user interface versus the baseline user interface. These results suggest that the elapsed event image viewer provides the operator useful capabilities for task resumption.
7. EXPERIMENT 3: EFFECT OF ALERT NOTIFICATIONS ON PERFORMANCE AND INTERRUPTION RECOVERY

7.1 Introduction

The primary focus of this final experiment is to study the effect of informing the user / operator / participant via alert notification on the emergence of a new task scenario that needs their attention.

The purpose of the experiment is to find out if such warning signals (alerts):

- are helpful in notifying the user regarding another task,
- do not cause distraction from the primary task, and
- make it easier for the user to gradually shift to a secondary task and initiate the task more efficiently than being abruptly forced into the secondary task without any warnings,

Another purpose is to study if the time span between the appearance of the alert and the beginning of the secondary task can be effectively used by the operator to create a mental picture of the primary task before switching tasks and hence resume the primary task quickly upon returning back to the same primary task.
7.2 Research questions and Hypotheses

1. Does the nature of the alert (visual alert to audio-visual alert) influence the time taken by human to detect notification regarding the impending secondary task?

**Hypothesis 1 (null hypothesis):** There is no difference in the time taken to detect and acknowledge the notification irrespective of the nature of the alert signal.

**Hypothesis 1 (alternate hypothesis):** Based on the nature of the alert signal, there is a difference in the time taken to detect and acknowledge the notification.

2. Does the nature of the alert (visual alert to audio-visual alert) affect the operator’s ability to stay longer on the primary task before switching to the secondary task?

**Hypothesis 2 (null hypothesis):** There is no difference of the effect of the nature of the alerting signal on how long the operator continues performing the primary task before switching to the secondary task that has begun.

**Hypothesis 2 (alternate hypothesis):** As a result of the nature of the alerting signal, there is a difference in duration for which the operator continues performing the primary task before switching to the secondary task that has already begun.

3. Does the time spent in the primary task during the alerting phase help the operator resume the primary task quicker on return compared to resuming the primary task after being abruptly interrupted?

**Hypothesis 3 (null hypothesis):** There is no difference in the primary task resumption time with or without the use of an alerting signal.

**Hypothesis 3 (alternate hypothesis):** There is difference in the primary task resumption time with the use of alerting signal.
4. Does the time spent in the primary task during the alerting phase help the operator gain change awareness more quickly on return compared to the condition of being abruptly interrupted from the task?

**Hypothesis 4 (null hypothesis):** There is no difference in the time taken to gain change awareness in the primary task with or without the use of an alerting signal.

**Hypothesis 4 (alternate hypothesis):** There is difference in the time taken to gain change awareness in the primary task as a result of an alerting signal.

5. Does the nature of the alert (visual alert to audio-visual alert) have an effect on the operator’s frustration level?

**Hypothesis 5 (null hypothesis):** There is no difference in the level of frustration experienced by the operator, comparing the two alerting types.

**Hypothesis 5 (alternate hypothesis):** Comparing the two alerting types, the level of frustration experienced by the operator is higher with the audio-visual alert.

### 7.3 Method

The experimental design was a 2 (tasks complexity) X 2 (alert technique) mixed factorial design with the alert type being a between subjects factor.

The independent variables in the design and their factor levels were:

- **Task Complexity:** Number of UAVs in the scenario (Within-subjects factor)
  - Simple primary task (2 UAVs) and simple secondary task (2 UAVs)
  - Complex primary task (4 UAVs) and simple secondary task (2 UAVs)

- **Alert Technique** (Between-subjects factor)
  - Visual alert (solid red color flashing block)
- Audio-Visual alert (a warning audio signal (beep-beep-beep with solid red color flashing block)

The dependent variables in experiment 3 are:

1. Alert detection time,
2. Time taken to switch to secondary task,
3. Primary task resumption time,
4. Time taken to gain change awareness, and
5. Level of Frustration experienced by participants due to the emergence of alerts – Using the NASA-TLX scale (Hart and Staveland, 1988)

7.4 Stimuli

Figure 49 shows a snapshot of the primary task screen that is displayed to the user. Moments before emergence of secondary task display, an alert or warning panel is displayed at the bottom right corner of the primary task screen. The panel is provided with a ‘Confirm’ button. When the operator presses the ‘Confirm’ button, it signifies acknowledgment of the alert and that they are ready to switch over to the secondary task.
Figure 49: Primary task UAV user interface with alert window (visual alert) at the bottom right corner

7.5 Participants

The participants in the research study were graduate and undergraduate students in Wright State University. They had a good knowledge of Windows-based applications and familiarity in operating the mouse and keyboard configuration.
7.6 Apparatus

The simulation was written in C#.net and runs on a 2.79 GHz personal computing system running Windows XP Professional with 1 GB memory. A 17-inch LCD monitor is used to display the interface, with a mouse and keyboard used as the input devices. The experiment was conducted in an office-like environment. The participants were seated in an adjustable office chair, with the mouse and keyboard placed at a comfortable position as determined by each participant.

7.7 Procedure

The procedure administered was similar to the procedure followed experiment 2. In addition, the participants were trained to respond to the alert system (visual alert and audio-visual alert).

Each participant performed two experimental trials; each trial was fifteen minutes in duration. Figure 50 shows the five timed segments in each trial. Unlike experiment 2, in these trials, the participants were warned of the secondary task using alert techniques. Since the independent variable, alert technique, was a between-subjects variable, one group of participants were presented the Visual alert while another group of participants were presented the audio-visual alert. All participants were presented all levels of the independent variable, task complexity.
7.8 Results

**Hypothesis 1 (null hypothesis):** There is no difference in the time taken to detect and acknowledge the notification irrespective of the nature of the alert signal.

Dependent variable: *Alert detection time:*

There is significant two-way interaction between Task complexity and Alert technique at $F(1, 14) = 11.055$, p-value = 0.005, variance = 9.031. Both main effects of task complexity and alert technique are also statistically significant at $F(1, 14) = 8.607$, p-value = 0.011, variance = 7.031 and $F(1, 14) = 6.463$, p-value = 0.023, variance = 11.281, respectively. Pairwise comparison for the main effect of alert technique corrected to a Bonferroni adjustment should that there was significant difference between the two alert types. On an average, alert detection was quicker with the audio-visual alert at 5.06 seconds while it took 6.25 seconds to detect the visual alert. Planned mean comparison on the two-way interaction revealed significant difference in alert detection time in the complex primary task scenario, as shown in Figure 51. In a complex task, alert detection was quicker with the audio-visual alert (5 seconds) compared to the visual alert (7.5 seconds).
Hypothesis 2 (null hypothesis): There is no difference of the effect of the nature of the alerting signal on how long the operator continues performing the primary task before switching to the secondary task that has begun.

Dependent variable: *Time taken to switch to secondary task*:

The two-way interaction between task complexity and the alert technique was statistically significant at $F(1, 14) = 64.960$, p-value $< 0.001$, variance $= 205.031$. Planned mean comparison showed that there was significant difference in the time taken to switch to the secondary task when performing a complex primary task. The participants’ time to switch tasks was slower (16.75 seconds) with the visual alert compared to 6.5 seconds with the audio-visual alert, see Figure 52. Both main effects of alert technique and task complexity were statistically significant at $F(1, 14) = 69.787$, p $< 0.001$, variance $= 215.281$, and $F(1,
14) = 97.040, p < 0.001, variance = 306.281. Pairwise comparisons for the main effect of both alert technique and task complexity corrected to a Bonferroni adjustment should that there was significant difference between the two alert types and there was a significant difference between the two levels of task complexity. Overall, participants exposed to the visual only alert took 11.125 seconds to perform a task switch while, during the audio-visual condition, only 5.938 seconds was taken to switch tasks. In a simple primary task condition, participants took only 5.438 seconds to switch to the secondary task, while in a complex primary task condition, 11.625 seconds was taken to switch tasks.

**Figure 52**: Graph depicting the time taken to switch to secondary task while being alerted by two different techniques
**Hypothesis 3 (null hypothesis):** There is no difference in the primary task resumption time with or without the use of an alerting signal.

Dependent variable: *Task resumption time:*

In the statistical analyses for hypothesis 3, the ANOVA model constructed was a 2 x3 mixed design. The between subjects factor, alert technique, had three levels: no alert, visual alert, and audio-visual alert.

Statistical analyses showed a two-way interaction effect between task complexity and alert technique was not significant. The main effect of alert technique was statistically significant at $F (2, 21) = 20.725$, $p < 0.001$, variance $= 307.938$. Pairwise comparison for the main effect of alert technique corrected using the Bonferroni adjustment showed a significant difference of the two alert techniques from the no alert condition. When the primary task was complex, resumption with the visual alert was quicker compared to the no alert condition.

**Figure 53:** Graph comparing the primary task resumption time due to alerts and no alerts
**Hypothesis 4 (null hypothesis):** There is no difference in the time taken to gain change awareness in the primary task with or without the use of an alerting signal.

Dependent variable: *Time taken to gain change awareness:*

The ANOVA model constructed for this hypothesis was similar to hypothesis 3. The two-way interaction between task complexity and the alert technique was statistically significant at $F(2, 21) = 5.866$, p-value $= 0.009$, variance $= 66.396$. Planned means comparison showed that when the primary task scenario was simple, there was a significant difference in the change awareness time between the no alert scenario and the scenario with alerts. In the ‘no alerts’ scenario, Change awareness took maximum time (32 seconds) when the operator was recovering in the ‘no alerts’ setting., in a simple primary task – simple secondary task trial. However, in the complex primary task scenario condition, the change awareness time of the ‘no alert’ scenario was relatively lower than the scenario with visual alert. Actually, change awareness was lower while recovering from a complex task than a simple task, which was surprising because, in the complex task, the operator would have to gain situation awareness related to 4 UAVs and the terrain.
Figure 54: Graph depicting the time to gain change awareness between scenarios with alerts and no alert scenarios

Hypothesis 5 (null hypothesis): There is no difference on the level of frustration experienced by the operator between the two alerting types.

Dependent variable: Frustration level measured on the NASA-TLX scale:

The frustration level scale experienced by participants as a result of the alerts was measured using the NASA-TLX scale measurements. Statistical analyses showed that the main effect, alert technique, was statistically significant at $F(1, 14) = 74.153$, p-value $< 0.001$, variance $= 19.531$. Pairwise comparison on alert technique using a Bonferroni correction showed that there was a significant difference in frustration level between the two alert techniques. Participants’ frustration was significantly higher at 3.688 with the audio-visual alert compared to a 2.125 scale value with the visual alert, see Figure 55.
7.9 Discussion

Two alert techniques were developed and tested in experiment 3 to understand whether alerts positively affect operator performance in a time-critical environment. The two alerts were:

1. Visual alert – a solid color flashing block, and

2. Audio-visual alert – a solid color flashing block with a beep-beep audio signal.

Results showed that the audio-visual alert was detected faster than the visual alert; the use of sound speeds detection.

Results showed that with the visual alert, the operators took a significantly longer time to switch to the secondary task, especially when the primary task scenario is complex (consisting of 4 UAVs). This can be of concern when the secondary task is critical and delays in the task switch should be avoided.
Even though the audio-visual alert seemed to perform significantly better than the visual alert, the frustration level scale as measured using the NASA-TLX scale showed that the frustration level was higher using the audio-visual alert versus the visual alert. The operators indicated that the audio-visual alert disturbed them so they waited for the secondary task to emerge so that they could switch to it removing the alert. This helps explain the task switch time difference.

There were problems with the visual alert as well. Operators complained that during the time when the visual alert was active, it distracted their attention from the status-at-a-glance display, especially when the operators were trying to view the lower part of the display containing information on the terrain.

While the alerts seemed to help, it is clear additional work is needed to define the visual, audio, and placement guidelines associated with alerts in dual-task environments.
8. RESEARCH CONTRIBUTION AND SIGNIFICANCE

8.1 Research Background

Complex dynamic systems that require the human operator to plan and monitor missions such as in the case of remotely operated vehicles, can heavily overload the operator’s cognitive capacity (Sheridan, 1992). Cummings et al. (2006) mention that even if the information complexity in the system does not increase, the mental workload on the human operator of the system will increase with time. Any increase in complexity will usually result in increased workload and increased unpredictability of the system, negatively impacting the human and system performance (Miller, 2000). In an effort to determine if display techniques used in the operator interfaces improve or affect the human performance, Cummings (2005) performed an experiment in which she varied the number of color categories and the number of system entities. She determined that display complexity factors such as the number of color categories used on the operator interface for presenting the information affected the human performance to a more significant extent than the environmental factors such as increasing the number of system entities to be controlled by the operator. This signifies that it is important that the operators are provided with interface features that assist them in interacting with the system and also, effectively manage the increasing level of information complexity.

In human supervisory control, the system process is either automated or semi-automated and the human monitors the system. Monitoring necessitates three responsibilities
from the operator: the constant observation of the critical parts of the system and its components, awareness of overall situation at all times, and the capability to detect faults or problems in the system (Sheridan, 1999). In monitoring tasks, allocating the operator attention among various system components is a difficult task and humans can be slow in shifting attention between different parts of the system (Sheridan, 1999). Under such circumstances, when we look at a dual-task scenario environment, where both task scenarios require significant amount of monitoring and control from the human, the design of the operator interface should focus on actions such as:

1. allocating attention to different system components in the primary task scenario,
2. shifting the attention to the secondary task scenario,
3. resuming the ‘primary’ task scenario after finishing the secondary task scenario, and
4. maintaining the operator situation awareness and mental workload during the entire dual-task monitoring and control activity.

8.2 Research Summary

This dissertation provided an in-depth survey of research on decision support systems and user interface design. An analysis of the survey yielded a discussion of gaps in the current knowledge associated with user interface design. The analysis also yielded initial guidelines for interface design associated with complex, dynamic dual-task environments.

Three separate experiments were conducted. Experiment 1 used an off-the-shelf gaming environment to examine the effect of interruptions on trust issues in team decision-making environments. Using the developed guidelines, two interfaces were constructed: a baseline interface and an advanced interface. A suite of operational scenarios were devised
and embedded within a simulation. Two subsequent experiments were conducted examining research issues associated with user interfaces for dual-task complex environments.

8.3 Research Contribution

The contributions of this research study on complex, dynamic, supervisory control dual-task scenarios to the body of knowledge are:

a. Development of single operator user interfaces on a 17-inch display screen for performing supervisory monitoring and control of a time-critical dual-task scenario environment where both task scenarios are information rich and time-critical and at any instant only one task scenario can be viewed on the screen and controlled by the operator.

b. Defined a general set of operator interface design guidelines for dual-task scenarios.

c. Design and development of visualization methods to assist the human operator in rapid re-assessment of a primary (interrupted) task situation and hence resumption of the primary task. Conducted empirical analyses using human participants to study the effect of such visualization methods in both the primary and secondary tasks.

d. Design and development of visualization methods to assist a human operator in successfully planning a course of action for a mission and allow re-planning during any time of the mission for improving and adjusting the course of action. Conducted empirical analyses using human participants to study their effectiveness.

e. Design and development of status-at-a-glance displays for dual-task scenarios and conducted empirical analyses to study the effect of such displays in maintaining situation awareness.
f. Design and development of multi-modal alert techniques on small screens for dual-task scenarios. Conducted empirical analyses to study their effect in notifying the human operator about a secondary task scenario.

8.4 Significance of this research

a. One of the first research studies focused on the design and implementation of interface features for dual tasks scenarios, monitored and controlled by an individual operator on a small screen display unit and where both the primary and secondary task scenarios are equally complex with respect to information richness and time criticality, and both the task scenarios have domain similarity.

b. Defined a general set of operator interface design guidelines for dynamic dual-task scenarios and verified these guidelines by experimentation on a scenario-based design.

c. Designed resumption interface cues for retrieval of attention and situation awareness and resumption of the primary task after interruption, that is, quick comprehension of the current situation (level 2 SA).

d. Designed planning interface cues that help operators in interpretation of the future status of the system and its components based on actions performed on the current situation thus supporting the operator in obtaining level 3 SA and assisting the operators in performing extensive mental simulations.

e. Extended the use of status-at-a-glance displays in secondary task scenarios and determined its effect on human performance.
f. *Determined display features and their layout in a status-at-a-glance display* and examined whether the layout should change between low complexity and high complexity situations, where the complexity is measured in terms of the information volume and content of the task scenario.

g. *Extended the use of multi-modal alert techniques* to dual-task scenarios for notifying the operator about initiating the secondary task.

h. *Integrated the resumption interface cues into the status-at-a-glance display* and studied their effect on operator situation awareness and mental workload.

i. *Determined the effect of display attributes* (size of the display, position of the display on the screen, and *color categories* used in the display feature) of the resumption interfaces cues, course of action planning cues, status-at-a-glance displays, and alert techniques on human performance.

j. Studied the *effect of image data feed* through the display interface to the operator.

k. Studied the *effect of interruptions on trust and coordination*, and hence performance among team members performing tasks in small global virtual environments and hence the requirement for visual displays.

l. Studied *mode awareness* in participants in the advanced user interface when displaying a color-coded representation in the current system mode, and no use of color in the baseline user interface.
8.5 User Interface Design Guidelines

The final user interface design guidelines, updated from those in section 4.5.1, have been listed below. The guidelines can be classified into ‘design only’ guideline or ‘design and evaluation’ guideline. The ‘design only’ guidelines are represented with a ‘D’ while the ‘design and evaluation’ guidelines are represented with a ‘D+E’. The user interface design guidelines are:

1. For time-critical dynamic dual-task scenarios environment, a primary requirement is an at-a-glance display that assists the operator obtain information quickly and maintain situation awareness. Both the primary and secondary task user interface should contain this at-a-glance display component. (D)

2. Interruption recovery assisting components such as the Elapsed Events Image Viewer can be designed to show events that occurred during interruption to gain change awareness rapidly and hence resume the interrupted task quickly and effectively. (D)

3. Irrespective of whether the task scenario is a primary or secondary task, if it involves decision making activities, then the design of solution explorers such as the route analyzer can assist the operator in performing the tasks quickly and accurately while also helping in maintaining the SA. (D)

4. The use of alert techniques (uni-modal and multimodal alerts) that notify individuals or operators regarding an impending interruption should be designed and integrated. (D+E)

5. In highly complex dynamic environments, if the primary task and the secondary task scenarios are unrelated, then it is better to not display the secondary task display interface while performing the primary task. In other words, it is preferable that no information
about the secondary task be shared with the operator currently involved in the primary task scenario. (D+E)

6. Similar color categories should not be used in the primary and secondary task scenarios, especially if the color type is going to convey different information in the task scenarios. (D+E)

7. Icons and symbols convey information quickly and accurately to the human. System components should be represented as icons and changes in the state of the components should be shown using changes in icon representation, thus extending work from a single task scenario environment to a dual-task scenario environment. (D+E)

8. When designing a user interface for a particular scenario, a good practice is to have all information display components for that scenario available and viewed at the same time. The user must not be required to toggle between two or more display screens to obtain complete information. In experiment 1 where the participants had to toggle between the scenario display and the map display, this was found to be less effective than a single integrated display. (D+E)
APPENDIX A

Paperwork for Experiment 1

CONSENT FOR PARTICIPATION IN RESEARCH

Experiments and Environments to Examine and Test Issues in Sense and Respond Logistics

AGREEMENT TO PARTICIPATE:
"This signed consent is to certify my willingness to participate in this research study."

PURPOSE OF STUDY:
"The purpose of this research study is to examine the effects of trust facilitating interventions on team performance in a gaming environment. I am being asked to participate in the study because I am a healthy volunteer.

PROCEDURE(S):
I will be playing a military simulated game on a team with two other players. As a team we will perform a series of military related tasks involving transporting either important people or supplies from one place to another using a gaming simulator called Virtual Battlespace 1. We will have to work together to complete the missions given to us.

I will be assigned to either a control group or an experimental group. If I am assigned to the control group, I will participate in the game as is, with no controlled interaction with my team mates. If I am in the experimental group, I will be allowed some interaction with my team mates prior to and during the mission via the chat tool in the game. The study will take about one and a half hours to complete and I will be allowed a break if necessary.

BENEFITS AND RISKS:
There is a minimal risk of eye strain associated with this research study. There are no direct benefits to me for participation in this study.

ADDITIONAL COSTS:
There are no additional costs to me from this research.

ALTERNATIVES:
Not applicable

REMUNERATION:
I will receive $10 for my participation and an additional $10 if I win the game.

CONFIDENTIALITY:
Any information about me obtained from this study will be kept strictly confidential and I will not be identified in any report or publication.
COMPENSATION FOR INJURY STATEMENT:
Reasonable and immediate medical attention, as exemplified by the student health services of the Frederick A. White Health Center, will be provided for physical injury caused directly by participating in this protocol. Any financial compensation for such physical injury will be at the option of Wright State University, and decided on a case-by-case basis. Additional information can be obtained from the office of General Counsel, (937) 775-2475.

STUDY RESULTS
The group results from the research can be obtained beginning January 1, 2008 by contacting Dr. Misty Gripper via misty.gripper@wright.edu

WHOM TO CONTACT:
If I have questions about this research study, or have a research-related injury to report, I can contact the researcher Misty Gripper at 937-775-5116. If I have general questions about giving consent or my rights as a research participant in this research study, I can call the Wright State University Institutional Review Board at 937-775-4462."

VOLUNTARY CONSENT:
I am free to refuse to participate in this study or to withdraw at any time. My decision to participate or to not participate will not adversely affect my care at this institution or cause a loss of benefits to which I might otherwise be entitled.

My signature below means that I have freely agreed to participate in this investigational study.”

SIGNATURE/DATE LINES:
(Name/Signature of Participant) (Date)

(PI) or (Person Authorized to Obtain Consent**) (Phone No.) (Date)

FOOTER: (Title of study or other identifier; form version number; date of version; page number; and participant signature/initials line should be on each page.)
GAMEPLAY INSTRUCTIONS

Welcome to the Virtual Teams Study. All participants will receive $10 for taking part in this study. Teams that complete all the missions effectively and efficiently will receive an additional $10 at the completion of the study. Please read these and other instructions carefully to increase your chances of obtaining the additional $10.

To your right you will find a key map, which list the functions each key is used for within the VBS 1 simulation. The following will walk you through a brief tutorial, which will allow you to better familiarize yourself with the game. This is a brief tutorial and should take no longer than 10 minutes to complete. Please read though and familiar yourself with the game in a timely fashion.

Team Communication:
To communicate with your team press / . Once you have typed your message, simply press ENTER to send your message to your teammates.

There are also several chat channels, which can be selected by using the comma ( , ) and period ( . ) keys. During this study it is not necessary to change the channel you are speaking in, but if you accidentally change the channel you can use the comma and period to get back to the default channel, which is the SIDE CHANNEL.

If at any time you have a question during this tutorial, simply send a message saying “Help” and someone will come to answer your question.

Looking around the environment:
To begin, move the mouse cursor around. The mouse is used to control your view, the direction you are moving in, and to steer vehicles. To look up, move the mouse forward, to look down, move the mouse backward. To turn your view left or right, or to steer a vehicle to the left or right, simply move the mouse in that direction.
**Basic Movement:**
Movement is done with the W, A, S, D keys, similar to most First-Person Shooters. W will move your character forward or accelerate your vehicle; S will move your character backward, stop your vehicle, or if held, move your vehicle in reverse. A will make your character side step to the left, or turn your vehicle to the left. D will make your character side step to the right, or turn your vehicle to the right.

When driving a vehicle, it is recommended that you use the mouse to steer, as the A and D keys can sometimes be unresponsive. To run, simply press E, or hold the SHIFT key while pressing W. This method also works when driving a vehicle, and will make you accelerate beyond the normal driving speed.

There are also several standing positions your character can take, such as crouching or going prone (laying down). To crouch, simply press Q, to stand up again, press Q once more. To go prone, press Z, and press Z again stand up.

**Vehicle Use:**
To enter a vehicle, walk up to the driver side door and a menu will appear in the bottom right corner. In this menu you are presented with several options including:

1. get in the vehicle as the driver (get in as driver),
2. ride as a passenger (ride in back),
3. enter the gunner positions (get in as gunner).

Using the bracket keys ( [ and ] ), you can move the selector through the list of choices available in the list. Once you have highlighted the position you wish to enter in a given vehicle, press ENTER on the keyboard to enter that position. If for any reason this menu does not appear, simply press one of the bracket keys and it should appear. When inside a vehicle, coming to a stop or pressing one of the bracket keys will bring up the commands menu in the bottom right corner. To exit a vehicle, highlight the “get out” option, and press ENTER on the keyboard.

Some vehicles contain weapons and items such as grenades and binoculars. These items are considered off limits to your squad, and removing them from vehicles will result in a mission failure.

Once you are inside a vehicle, you can press the ENTER key on the Number Pad to switch to a third-person view. This view makes driving certain vehicles much easier, and can be used at your own discretion.

This completes the VBS 1 familiarization. When you have driven to the airport and exited your vehicle please wait for further instructions.
The neighboring island of Al-Almar was recently taken over by the head of the military, Miyindi Amin.

Coalition forces from several countries are moving equipment and supplies to the neighboring island of Andaman. You are among the forces that have already arrived on Andaman that are helping prepare the military buildup that will be required to take back Al-Almar. The Americans have amassed several regiments on the island already, and are now inventorying equipment and units to ensure that all of the necessary items are in position.

In this scenario you will be playing the role of soldier Alpha, who is part of a team of logistics support staff. You and your teammates are responsible for locating and verifying intelligence reports on the number of units or pieces of equipment that are on the island. When you receive a mission from your commander, drive to the stated location, perform the mission task, report back your findings to the commander, and then wait for further orders.

It is important to remember that you are not equipped to engage enemy contacts. If for any reason you come in contact with an enemy, it is best to leave the area as quickly as possible. It is critical that coalition forces avoid escalating hostilities in the area. Any hostile actions initiated by you or any other members of your logistics team will be considered a mission failure.
COMMANDER INFORMATION SHEET

Background
The neighboring island of Al-Almar was recently taken over by the head of the military, Miyindi Amin. Coalition forces from several countries are moving equipment and supplies to the neighboring island of Andaman. You are among the forces that have already arrived on Andaman that are helping prepare the military buildup that will be required to take back Al-Almar. The Americans have amassed several regiments on the island already, and are now inventorying equipment and units to ensure that all of the necessary items are in position.

Your Role
In this scenario you will be playing the role of the Commander of a logistics squad consisting of two soldiers, Alpha and Bravo. As the commander, it is your responsibility to assign missions to both soldiers, keep records of units available, and ensure that enough units are present on the island for the upcoming conflict. You will receive Mission Orders from headquarters sporadically, and it is your responsibility to ensure that your soldiers complete the tasks accurately and in a timely fashion.

It is important for you to remain in your logistics role, as you and your team are not properly equipped to be members of a combat unit. It is critical that coalition forces avoid escalating hostilities in the area. Any hostile actions initiated by you or your logistics team members will be considered a mission failure.

Your Team
The soldiers you are working with have recently deployed and are extremely inexperienced. They may have difficulty following the terrain using the provided map, and recognizing the equipment they are asked to report on. It is critical that you, as commander, provide accurate information up the chain regarding resources available. You must decide whether the intel provided with the mission or the eyes-on-report from the alpha and bravo soldiers is most reliable.

Reports
Attached to each Mission Order is a Mission Report. These reports will be sent back to headquarters, along with your final count of units, to determine what resources are needed. Mission Reports also have a space for additional information. In this area you are free to write down any mission critical information that may be reported to you during the course of a mission, such as enemy contact. See the attached sheet for an example of how to fill out a Mission Report.

Mission Checklist
Along with the example Mission Report, you will also find attached to the back of this document your Resource Checklist. This document is to be used by you throughout the scenario to keep track of equipment and supplies. In the “Accounted For” column you will indicate the number of each unit type accounted for. In the “Number Requested” column you will indicate the number of additional units requested (if any) to meet the mission needs. After the scenario is complete, you will turn in the Resource Checklist, with your final counts for equipment and the number of units you still need to meet the mission goals.

Begin Play
After you have reviewed the example Mission Report and feel comfortable with your position as commander, send a message to your team stating “I am your new commander, I will be issuing you orders from now on.” Once you have done this Mission Orders will begin to arrive.
RESOURCE CHECKLIST

<table>
<thead>
<tr>
<th>Unit Type</th>
<th>Accounted For</th>
<th>Total Needed</th>
<th>Number Requested</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel Truck</td>
<td></td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Ammo Truck</td>
<td></td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Troop Truck</td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Bradley Fighting Vehicle</td>
<td></td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Tank</td>
<td></td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Helicopter</td>
<td></td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Soldier</td>
<td></td>
<td>45</td>
<td></td>
</tr>
<tr>
<td>Anti-Tank Soldier</td>
<td></td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Medic</td>
<td></td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Officer</td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Humvee</td>
<td></td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Ambulance</td>
<td></td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>

Use this form to track resources throughout the scenario. This page will be turned in at the end of the scenario with your finally tally count.
Situation Awareness Calibration

It is key that the teams maintain a shared awareness of the current situation throughout the scenario. Each player will have information that the others do not. In order to work effectively as a team, it is important that each play convey key information to the others, while avoiding overloading communication channels with extraneous chat.

In this scenario, you will be asked to use a situation awareness calibration strategy to facilitate information sharing without overloading communication channels. Approximately every 10 minutes the commander will state current mission goals for each soldier, and ask each soldier to report on current status on assigned mission, enemy activity, and any other elements that put the mission at risk. In addition, team members are encouraged to share information about the situation and the mission outside of the scheduled situation awareness calibration if they believe others on the team need the information immediately.

The commander should initiate a situation awareness calibration approximately every 10 minutes. Soldiers should expect to respond to the commander’s questions every 10 minutes.

**Situation Awareness Calibration procedure**
1. Commander states current mission goals
2. Commander asks the following questions to each soldier:
   2.1 What is your current status?
   2.2 Is your mission clear?
   2.3 Have you seen any indication of enemy activity?
3. Each soldier provides commander information about anything encountered that might affect the mission.

Please note, in addition to the situation awareness calibration, any team member may share information at any time if they believe other members need the information to complete the mission.
## MISSION DELIVERY TIME

<table>
<thead>
<tr>
<th>Time</th>
<th>Order Number for Alpha and Bravo</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1 Alpha, 1 Bravo</td>
</tr>
<tr>
<td>4:00</td>
<td>2 Alpha</td>
</tr>
<tr>
<td>8:00</td>
<td>2 Bravo</td>
</tr>
<tr>
<td>11:00</td>
<td>3 Alpha</td>
</tr>
<tr>
<td>16:00</td>
<td>3 Bravo</td>
</tr>
<tr>
<td>19:00</td>
<td>4 Bravo</td>
</tr>
<tr>
<td>21:00</td>
<td>5 Bravo</td>
</tr>
<tr>
<td>25:00</td>
<td>4 Alpha</td>
</tr>
<tr>
<td>33:00</td>
<td>5 Alpha</td>
</tr>
<tr>
<td>38:00</td>
<td>6 Bravo</td>
</tr>
<tr>
<td>40:00</td>
<td>6 Alpha</td>
</tr>
<tr>
<td>42:00</td>
<td>IMMEDIATE MISSION</td>
</tr>
<tr>
<td>44:00</td>
<td>7 Bravo</td>
</tr>
<tr>
<td>48:00</td>
<td>7 Alpha</td>
</tr>
</tbody>
</table>
MISSION ORDERS (DELIVERED BY COMMANDER TO ALPHA/BRAVO)

Order 1
SEND ALPHA SQUAD TO DAR AL-HARB
MISSION: COUNT NUMBER OF FUEL TRUCKS PRESENT IN DAR AL-HARB. ACCURATE COUNT IS CRUCIAL TO MISSION SUCCESS.

INTEL: RECENT SATELLITE IMAGERY SHOWS TWO FUEL TRUCKS CURRENTLY PRESENT IN THE TOWN.

Order 1
SEND BRAVO SQUAD TO HARG
MISSION: COUNT NUMBER OF AMBULANCES PRESENT IN HARG. ACCURATE COUNT IS CRUCIAL TO MISSION SUCCESS.

INTEL: RECENT SATELLITE IMAGERY SHOWS TWO AMBULANCES CURRENTLY PRESENT IN THE TOWN.

Order 2
SEND ALPHA SQUAD TO HARG
MISSION: COUNT NUMBER OF AMMO TRUCKS PRESENT IN HARG. ONE AMMO TRUCK MUST BE RETURNED TO THE AIRPORT. ACCURATE COUNT IS CRUCIAL TO MISSION SUCCESS.

INTEL: RECENT SATELLITE IMAGERY SHOWS THREE AMMO TRUCKS CURRENTLY PRESENT IN THE TOWN.

Order 2
SEND BRAVO SQUAD TO THE NORTH OF DAR AS-SUTH
MISSION: COUNT NUMBER OF TANKS PRESENT IN DAR AS-SUTH. ACCURATE COUNT IS CRUCIAL TO MISSION SUCCESS.

INTEL: RECENT SATELLITE IMAGERY SHOWS TWO TANKS CURRENTLY PRESENT IN THE TOWN.

Order 3
SEND ALPHA SQUAD TO THE SADH OUTPOST.
MISSION: COUNT NUMBER OF SOLDIERS PRESENT AT THE SADH OUTPOST. WE MUST ALSO KNOW THE NUMBER OF ANTI-TANK SOLDIERS PRESENT AMONG THE SOLDIERS AT THE OUTPOST. ACCURATE COUNT IS CRUCIAL TO MISSION SUCCESS.
ONCE ALL SOLDIERS HAVE BEEN ACCOUNTED FOR, A FUEL TRUCK PRESENT AT THE OUTPOST NEEDS TO BE TRANSPORTED TO DJEBEL GABR.

INTEL: RECENT SATELLITE IMAGERY SHOWS FIFTEEN SOLDIERS, WITH THREE ANTI-TANK SOLDIERS AMONG THEM CURRENTLY PRESENT IN THE TOWN.
Order 3
SEND BRAVO SQUAD TO MUT
MISSION: COUNT NUMBER OF SOLDIERS PRESENT IN MUT. ACCURATE COUNT IS CRUCIAL TO MISSION SUCCESS.

INTEL: RECENT SATELLITE IMAGERY SHOWS TWENTY-SIX SOLDIERS CURRENTLY PRESENT IN THE TOWN.

Order 4
SEND ALPHA SQUAD TO DJEBEL GABR.
MISSION: COUNT NUMBER OF HELICOPTERS AND HUMVEES PRESENT IN DJEBEL GABR. ACCURATE COUNT IS CRUCIAL TO MISSION SUCCESS.

INTEL: RECENT SATELLITE IMAGERY SHOWS THREE HELICOPTERS AND THREE HUMVEES CURRENTLY PRESENT IN THE TOWN.

Order 4
SEND BRAVO SQUAD TO THE SADH OUTPOST
MISSION: COUNT NUMBER OF OFFICERS PRESENT AT THE SADH OUTPOST. ACCURATE COUNT IS CRUCIAL TO MISSION SUCCESS.

INTEL: RECENT SATELLITE IMAGERY SHOWS ONE OFFICER CURRENTLY PRESENT IN THE TOWN.

Order 5
SEND ALPHA SQUAD TO DJEBEL GABR.
MISSION: TRANSPORT A SOLDIER TRUCK FROM DJEBEL GABR TO MUT. ACCURATE COUNT IS CRUCIAL TO MISSION SUCCESS.

INTEL: RECENT SATELLITE IMAGERY SHOWS ONE TRANSPORT TRUCK CURRENTLY PRESENT IN THE TOWN.

Order 5
SEND BRAVO SQUAD TO DAR AL-HARB
MISSION: COUNT NUMBER OF BRADLEY FIGHTING VEHICLES PRESENT AT DAR AL-HARB. ACCURATE COUNT IS CRUCIAL TO MISSION SUCCESS.

INTEL: RECENT SATELLITE IMAGERY SHOWS FOUR BRADLEY FIGHTING VEHICLES CURRENTLY PRESENT IN THE TOWN.

Order 6
SEND ALPHA SQUAD TO MUT.
MISSION: COUNT THE NUMBER OF MEDICS PRESENT IN MUT. ACCURATE COUNT IS CRUCIAL TO MISSION SUCCESS.
INTEL: RECENT SATELLITE IMAGERY SHOWS FIVE MEDICS CURRENTLY PRESENT IN THE TOWN.

**Order 6**
SEND BRAVO SQUAD TO DJEBEL GABR
MISSION: COUNT NUMBER OF TANKS PRESENT AT DJEBEL GABR. ACCURATE COUNT IS CRUCIAL TO MISSION SUCCESS.

INTEL: RECENT SATELLITE IMAGERY SHOWS FOUR TANKS CURRENTLY PRESENT IN THE TOWN.

**TOP PRIORITY MISSION REQUEST**
A C130 HAS JUST CRASHED OUTSIDE OF MUT. SEND ALPHA SQUAD TO CHECK FOR SURVIVORS.

MISSION: SEARCH FOR SURVIVORS AT THE CRASH SITE. ACCURATE COUNT IS CRUCIAL TO MISSION SUCCESS.

INTEL: THERE IS NO INTEL AT THIS TIME.

**Order 7**
SEND BRAVO SQUAD TO THE NORTH OF DAR AS-SUTH
MISSION: FIND AND PROTECT THE DIGNITIARIES OUTSIDE OF DAR AS-SUTH.

INTEL: RECENT SATELLITE IMAGERY SHOWS TWO DIGNITIARIES CURRENTLY PRESENT IN THE TOWN.

**Order 7**
SEND ALPHA SQUAD TO THE NORTH OF DAR AS-SUTH.
MISSION: LOCATE, COUNT, AND GUARD THE DIGNITIARIES PRESENT OUTSIDE OF DAR AS-SUTH. ALPHA SQUAD MUST MEET UP WITH BRAVO SQUAD AND GUARD THE DIGNITIES. ACCURATE COUNT IS CRUCIAL TO MISSION SUCCESS.

INTEL: RECENT SATELLITE IMAGERY SHOWS TWO DIGNITIARIES CURRENTLY PRESENT IN THE TOWN.
**Post-Questionnaire**

1. Overall, the people on my team are very trustworthy

   1 2 3 4 5 6 7
   Strongly Disagree
   Strongly Agree

2. There is a noticeable lack of confidence among the people on my team

   1 2 3 4 5 6 7
   Strongly Disagree
   Strongly Agree

3. We have confidence in one another on this team

   1 2 3 4 5 6 7
   Strongly Disagree
   Strongly Agree

4. I can trust members of this team

   1 2 3 4 5 6 7
   Strongly Disagree
   Strongly Agree

5. There are times when members of this cannot be trusted

   1 2 3 4 5 6 7
   Strongly Disagree
   Strongly Agree

6. I have confidence in the members of this team

   1 2 3 4 5 6 7
   Strongly Disagree
   Strongly Agree

7. I feel I can trust the members of this team completely.

   1 2 3 4 5 6 7
   Strongly Disagree
   Strongly Agree
APPENDIX B

Paperwork for Experiment 2 & 3

INFORMED CONSENT FORM

TITLE: Visualization methods and User Interface Design Guidelines for Rapid Decision Making in Complex Multi-Task Time-Critical Environments

AGREEMENT TO PARTICIPATE: I have freely agreed to participate in this research study and understand that participation is voluntary. Refusal to participate will involve no penalty or loss of benefits to which I am otherwise entitled and I may discontinue participation at any time without penalty or loss of benefits to which I am entitled.

PURPOSE OF STUDY: The purpose of this research study is to determine how computer user interface features assist the human in making quick decisions in a complex dual-task scenario environment where the primary task is to monitor and control remotely operated vehicles (ROVs) on search and destroy mission and the secondary task is to monitor and route ROVs on surveillance mission. Experiments will be conducted using human participants.

PROCEDURE: I will be comfortably seated in front of the monitor with adequate lighting in the room, much like an office environment. I will be trained to use the user interface and how to carry out the two tasks: search and destroy task (primary task) and the routing task for surveillance (secondary task). During any given trial, I will perform both the primary task and the secondary task. In any given trial, during the primary task, I will have to monitor and control two to four ROVs traveling around specific paths covering targets, identifying them, and if the targets are enemy targets destroy them. During the process, I will be notified using alert techniques, such as
warning messages on the user interface, to switch to a secondary task. During the secondary task, I will have to monitor and route two to four ROVs on surveillance mission. After completing the secondary task, I will have to switch back to the primary task and continue performing the search and destroy tasks. I will participate in approximately 4 trials each lasting 15–20 minutes. After completing each trial, I will complete two questionnaires. The total time required for the experiment is approximately 2 hours.

BENEFITS AND RISKS:
There are minimal risks involved. I may experience fatigue, stress, or headaches from using the computer interface, similar to what you experience in typical word processing tasks. I will not receive any direct benefits.

REMUNERATION:
I will not be paid for my participation in this research study.

CONFIDENTIALITY:
I understand that no names or personal identifiers or social security numbers will be used in this study. The subject identification number that will be used is the last four digits of my university identification number and will be recorded on the questionnaire and linked to the data captured. Data related to human performance will be captured using modules implemented in the computer program used in the study. The collected data will be stored on the local hard disk and analyzed using statistics package. Questionnaire responses that will also be analyzed to determine human performance will be securely stored in the experimenter’s office desk. Information on individual performances will not be available, only group results will be reported.

WHOM TO CONTACT:
If I have any questions about this research study, I can contact Sriram Mahadevan @ mahadevan.2@wright.edu or Raymond Hill, Ph.D., Professor, 207 Russ Engineering Center, Wright State University @ ray.hill@wright.edu or @ 937 775 5150. If I have general questions about giving consent or my rights as a research participant in this research study, I can call the Wright State University Institutional Review Board at 937-775-4462.
VOLUNTARY CONSENT: My signature below means that I freely agree to participate in this research study. I have the right to stop participating in this study at any time. I have the right to see my data and to withdraw from the study at any time. If I want to receive information about the group results, I will provide my email address below. This indicates my request for summary results that will be sent to me after all data have been collected and analyzed by October 2008.

SIGNATURE/DATE LINES:

(Typed Name/Signature of Participant) (Date)

(E-mail address of Participant, if results are requested)

(Typed Name/Signature of Principal Investigator) (Date)
Visualization Methods and User Interface Design Guidelines for Rapid Decision Making in Complex Multi-Task Time-Critical Environments

Background and Procedural summary

1. PRINCIPAL INVESTIGATORS:

Sriram Mahadevan, 775-5044, 207 Russ Engineering Center, mahadevan.2@wright.edu
Raymond Hill, Ph.D., 775-5150, 207 Russ Engineering Center, ray.hill@wright.edu

2. OBJECTIVE:

The objective of this research is to determine how user interface design methods in a dual-task scenario environment support human operators in maintaining supervisory awareness in primary task situations, rapid assimilation when switching to a secondary task, and rapid re-assessment upon return to the primary task. Participants will use a desktop computer and interact with a Windows based interface using a mouse and keyboard. The primary task will be the control of ROVs in search and destroy mission and the secondary task will be the control of ROVs in surveillance mission. User interfaces that will be presented on the computer screen will provide the operator with information about targets, ROVs, and other objects in the area of the mission. Routing of the ROVs will depend upon factors such as amount of fuel remaining, number of targets already assigned, no-fly zones, priority of targets, and loiter time of ROVs. The performance measures that may be collected from the study include number of decision tasks completed, number of errors committed, time taken to resume the primary task, and mental workload.

3. BACKGROUND AND RELEVANCE:

Real-world scenarios are complex dynamic systems that are often information overloaded. Application domains such as search and destroy missions or real-time route planning provide time windows within which critical decisions must be made. The control of most of these systems is semi-automated. If two such applications were to be performed concurrently, the individual decision maker must assimilate lots of information and perform the tasks. This study focuses on the design of a small screen user interface with visual cues for performing multiple tasks, specifically supervisory control of remotely operated vehicle (ROVs).

4. IMPACT STATEMENT:

This research is critical for determining visualization methods and defining user interface design guidelines for effective performance in complex dynamic time-critical dual-task environments.
5. EXPERIMENTAL PLAN:

a) **Equipment/Facilities:** The experiment will take place in a laboratory room in the Russ Engineering Center. Subjects will use a desktop computer and interact with a Windows based interface via a mouse, keyboard, and monitor.

b) **Participants:** Participants will be recruited from the Wright State University student body. Potentials participants will be approached face to face within the Wright State University premises. If they are interested in participating in the study, it would be asked if they have over 5 years experience using a computer and if they can spend 2 hours of their time and whether they will participate without being paid. Further details are provided in Attachment 1.

c) **Duration of Study:** The experiment should last approximately 2 hours. Subjects are given freedom to withdraw from the study, anytime, for any reason, and are informed of this prior to the start of the study.

d) **Experimental Procedure and Data Analysis:** Subjects will be comfortably seated in front of the monitor with adequate lighting in the room, much like an office environment. Participants will be trained to use the user interface and how to carry out the two tasks: search and destroy task (primary task) and the routing task for surveillance (secondary task). During any given trial, participants will perform both the primary task and the secondary task. In any given trial, during the primary task, participants will have to monitor and control two to four ROVs traveling around specific paths covering targets, identifying them, and if the targets are enemy targets destroy them. During the process, the participants will be notified using alert techniques to switch to a secondary task. During the secondary task, the participants will have to monitor and route two to four ROVs on surveillance mission. After completing the secondary task, the participants will have to switch back to the primary task and continue performing the search and destroy tasks. Subjects will participate in approximately 4 trials each lasting 15 – 20 minutes. Subjects are designated by number (specifically university identification number) and not by name. Data related to human performance will be captured using modules implemented in the computer program used in the study. The collected data will be stored on the local hard disk and analyzed using statistics package (parametric and non-parametric methods). Questionnaire responses will also be analyzed to determine human performance. All experimental procedures and results will be documented. Results will be discussed and compared with past surveys only on qualitative basis.
e) **Safety Precautions:** Participants are told of steps to be taken and the location of exit doors in the event of power outage or fire.

6. **MEDICAL RISK ANALYSIS:**

   a) **Informed Consent:** Prior to participation in the experiment, the subjects will be informed of the possible risks involved. Before participation, each subject must sign the informed consent form.

   b) **Risk Assessment:** There are minimal risks involved. Participants may experience fatigue or stress from using the computer, similar to what you experience in typical word processing tasks.
ATTACHMENT 1
Questionnaire for Mental Workload Assessment

Subject # (Last four digits of Student ID) ____________

Please answer each question carefully and make any appropriate comments.

1. Was the training session enough for you to understand the task?
   a. Yes          b. No

2. How would you rate use of the interactive panel interface?
   Excellent 1 2 3 4 5 Poor

3. How much mental activity was required (Was the task easy or demanding?)?
   Low 1 2 3 4 5 High

4. How much time pressure did you feel due to the rate at which the tasks occurred?
   Low 1 2 3 4 5 High

5. How satisfied were you with your performance in accomplishing the goals?
   Good 1 2 3 4 5 Poor

6. How hard did you have to work to accomplish your level of performance?
   Low 1 2 3 4 5 High

7. How stressed and annoyed versus relaxed and complacent did you feel during the task?
   Low 1 2 3 4 5 High

8. Do you have any additional comments?
ATTACHMENT 2
Questionnaire for User Interface Satisfaction

Subject # (Last four digits of Student ID) __________

Please answer each question carefully and make any appropriate comments.

1. Characters on the screen:
   Hard to read 0 1 2 3 4 5 6 7 8 9 Easy to read

2. Highlighting on the screen simplifies task
   Not at all 0 1 2 3 4 5 6 7 8 9 Very much

3. Organization of information on screen
   Confusing 0 1 2 3 4 5 6 7 8 9 Very clear

4. Position of message boxes and alerts on the screen
   Inconsistent 0 1 2 3 4 5 6 7 8 9 Consistent

5. Learning to operate the system
   Difficult 0 1 2 3 4 5 6 7 8 9 Easy

6. Remembering names and use of commands
   Difficult 0 1 2 3 4 5 6 7 8 9 Easy

7. Tasks can be performed in a straight forward manner
   Never 0 1 2 3 4 5 6 7 8 9 Always

8. System speed
   Too slow 0 1 2 3 4 5 6 7 8 9 Fast enough

9. System tends to be
   Noisy 0 1 2 3 4 5 6 7 8 9 Quiet
REFERENCES


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Kirlik, A. C. (1989). The organization of perception and action in complex control skills, PhD dissertation, The Ohio State University, Department of Industrial and Systems Engineering, Columbus, OH.


Krosner, S. P. (1991). Using an extension of Rasmussen’s abstraction hierarchy as a framework for design of a supervisory control system of a complex dynamic system, PhD dissertation, Georgia Tech University, School of Industrial and Systems Engineering, GA.


