12th International Command and Control Research and Technology Symposium
Adapting C2 to the 21st Century

SHARED DISPLAYS: AN OVERVIEW OF PERCEPTUAL AND COGNITIVE ISSUES

Cognitive and Social Issues,
Network-Centric Experimentation and Applications,
C2 Technologies and Systems

Denise Aleva, Lisa Douglas, and Paul Havig

Denise Aleva
Research Psychologist/Optical Engineer
Crew Systems Interface Division (AFRL/HECV)
2255 H Street
Wright-Patterson AFB OH 45433-7022
Tel: (937) 255-0883
denise.aleva@wpafb.af.mil

ABSTRACT

Large screen shared displays are a standard fixture in almost all command centers, but are generally under-utilized. Many problems stem from the fact that these displays are repeater displays from individual workstations. Scaling from workstation display to large screen display does not guarantee that text will be large enough to be visible to all users. Color reproduction on projection displays does not automatically match that on workstation displays; text and symbology overlays on maps are often not discernible. Because the shared displays are repeaters, the operator's navigation and control icons, menus and pallets are visible on the shared displays and obstruct the view of displayed information. Shared displays often present what is called a *common operating picture, or* COP. The COP should be the basis of a common operational understanding, but they are often too cluttered, yet lack useful information. In today's complex environment of asymmetric warfare, effects-based operations and coalition forces, decision quality information is needed to support collaboration and synchronization of operations. This means delivering the right information at the right time in a clearly visible and easily understandable format that supports cognitive processes associated with decision making and collaboration. The present paper will discuss perceptual and cognitive issues associated with shared displays and COPs in command centers.

1. INTRODUCTION

Large screen displays have become commonplace in military command centers. Many have one or more "shared displays" made up of multiple large screen displays. One would expect these shared displays to complement individual workstation displays and enhance the warfighters' capability to perform the mission by supporting group decision making and collaboration as well as synchronization of activity across the many specialized teams within the command center. In broad, functional terms, the primary purpose of a shared display should be to help users integrate and manage information from a wide range of sources (Mynatt, Huang, Voite, & MacIntyre, 2003).

There are potential benefits for implementing a well designed large shared display in the C2 environment. Large displays could be designed to provide one location to display data derived from diverse sources, thus offloading an individual workstation display and facilitating team or multi-task performance, or information to oncoming shift personnel or visitors to the C2 center. A shared display may also help the group understand organizational goals and objectives. However, very few of the personnel working in these command centers will attest to their usefulness. The shared display is often regarded by those responsible for mission execution to be "eye candy" for visitors or "VIP screens" and they are therefore ignored.

One of the primary goals of the shared display is to facilitate situation awareness (SA). For the C2 environment, can personnel see and understand what is happening around them, and can they take this information and put it into a larger, organizational context? Will SA be the same for all individuals and all levels of command? Implementing a shared display in the C2 environment means addressing these questions and considering some important perceptual and cognitive issues.

Laboratory experimentation has made large display perceptual issues relatively easy problems to solve. Understanding the different between the display types available with today's technology, how the location of the display interacts with the viewing distance and viewing angle, and measurements of color, contrast, and illumination, are all perceptual issues that should be addressed with the implementation of a shared display system.

A much more difficult challenge for a large shared display is determining how the shared display system will deliver decision quality information to the warfighter. Unfortunately, many of the research questions central to large display cognitive issues, such as SA, task support and performance, content relevance, and human interaction with the shared display have still not been answered in a manner generalizable to the C2 environment. We can address the issues in this paper, but offering domain-specific solutions for shared display issues in the C2 environment falls under the purview of an analysis tool called a cognitive task analysis (CTA). We will discuss CTA in further detail later.

The primary goal of this paper is to present an overview of perceptual and cognitive human factors issues regarding shared display implementation, task performance with large displays, and facilitating SA with a large shared display. For organization, the paper is divided into two main sections covering perceptual and cognitive issues. We will conclude with a section outlining the current and future research programs at the Air Force Research Laboratory Human Effectiveness Directorate. Unfortunately, time and space constraints prevent the authors from providing in-depth information a reader might want or need to plan and implement a shared display system. In an effort to provide as much information as possible, a more detailed list of readings and references can be found in Appendix A.

1.1 Recent observations.

From July 2005 – May 2006 an Air Force Research Laboratory (AFRL) led Human Systems Integration (HSI) Tiger Team evaluated the current state of HSI within the Air Operations Centers (AOC) and Distributed Common Ground System (DCGS) weapon systems. The team conducted observations at several AOC events including the Joint Expeditionary Force Experimentation 2006 (JEFX 06), an exercise for evaluating C2 tools in a simulated warfare environment. The findings were documented in an AFRL draft technical report submitted to the C2ISRC.

A general observation of our HSI Tiger Team was that the shared displays within AOCs are under-utilized. The under-utilization occurs for a variety of reasons. Many problems stem from the fact that the shared display is primarily composed of repeater displays from individual workstations. Scaling from workstation display to large screen display does not guarantee that text will be large enough to be visible to all users. Color reproduction on projection displays does not automatically match that on LCD workstation displays; text and symbology overlays on maps are often not discernible. Because the shared display are repeaters, the operator's navigation and control icons, menus and pallets were visible on the shared display and obstructed the view of displayed information.

Every AOC shared display includes a Common Operating Picture (COP) display whose purpose seems to be to provide a top level composite view of the air tasking order (ATO) plan and execution. While the COP should be the basis of a common operational understanding, it is of little value. The COP display at JEFX 06 displayed all or most of the air assets with no status or relevance information. Key operational areas such as AR and CAS were not shown. The COP was too cluttered, yet lacked useful information.

Darling & Means (2005) studied a group of 16 participants at JEFX 2004 where a large shared display was present during the exercise. Eight participants in the study reported they never looked at the shared display. Five of the other 8 participants reported looking at the shared display only on occasion. These participants reported that the COP information on the shared display was "not appropriate for me/for my level." One reason for this may be the shared display was a repeater of the individual workstation, as reported by 1 participant in the Darling & Means study. Three noteworthy recommendations for shared display design that resulted from this study were 1) make sure the individual workstation is not a repeater of the shared display; 2) provide small, collaborative displays for sub-groups working within the C2 environment, and 3) provide high-level data that is graphically represented. A repeater display is an individual workstation or desktop computer displaying exactly the same information, in an exactly the same layout, as the shared display. By definition, however, shared displays come in many sizes, forms, and configurations.

2. WHAT IS A SHARED DISPLAY?

The term "shared display" covers a range of definitions, even within the C2 environment. A general definition – large-scale computer information systems designed to provide decision support and facilitate situation awareness – is not a complete representation of either the form or function of a shared display.

In our technological era, we generally represent *display* in the form of electronic media (such as a desktop or wall-mounted monitor), but a flipchart or whiteboard can, by form (and function), be considered a shared display. When people think of *shared displays*, they may imagine a large wall display viewable by very large groups of people, like a room-spanning display found in a C2 center, or a bank of airport computers reporting departure and arrival times. The perceived function of the display is also dependent on the observer. This is a cognitively complicated concern and will be discussed in a later section. But shared displays come in many sizes. They are designed to support the activities of small groups (eight people of less), large groups (eight to 20 people) and very large groups (20+ people).

Figure 1. Alaverez & Jedrysik Interactive Shared display.

Similar to computer monitors found in desktop configurations, a small group shared display could be either a plasma or LCD flat panel screen measuring 36" – 48". These types of displays are becoming ubiquitous in military, business, and academic settings. The usual function of a small group display is to facilitate the collaboration and interaction of two or more people, but these displays can also serve as a non-interactive form of public information sharing.

Large group shared displays generally range from 6' – 15' and are usually front or rear projection screens. These displays are similar to the displays one might see in a conference room or lecture hall, with a large screen displaying images from a projector. Like small group displays, large group displays lend themselves to interaction by multiple users. They retain the function as both a collaborative and interactive tool, as well as a way to summarize or share information. Figure 1. shows an example of a large group shared display. Designed by Alvarez & Jedrysik (2006) of the Advanced Visualizations and Interactive Displays (AVID) team at Air Force Research Laboratory Information Directorate, the Interactive Shared display (IDW) consists of approximately 3.9 million pixels spanning an area of 12'x3¼' with a 9'x2¼' viewing area. Since current technology cannot accommodate the resolution needed to provide quality viewing for a single display of this size, displays for large groups usually consistent of an expanse of connected projection, plasma, or LCD displays. The convergence of displays may be invisible to the user (seamless) or appear as many displays side-by-side. Figure 1. illustrates an invisible, or seamless, connection of three rear projection screens; Figure 2. is an example of a tiled display.

Figure 2. Shared display at 2000 War Game. Darling & Means (2005)

Often referred to as a Knowledge Wall (K-Wall) or Data Wall, a very large group shared display is designed to be viewed by groups of more than 20 people. One of this paper's authors observed an Air Operations Center exercise where a large shared display measuring 102 feet in length was simultaneously viewed by more than 100 people. In contrast to small and large group displays, very large displays function primarily as a summary and information sharing tool, and as a means to facilitate situation awareness. Interaction with very large shared displays is usually limited to a

Figure 3. A very large group shared display in a command center at Dell Computer, Inc.

small group of users who have the authority to update or change information on the display. The size of a very large group display is limited by not only the size and location of the actual display, but also the location of the users. Figure 3. shows the very large group shared display and layout of Dell Computer, Inc.'s customer command center.

3. PERCEPTUAL ISSUES – "Can I see it? Can I read it?"

First things first. If the user of a shared display cannot see or read the information presented, the display has little or no value in supporting task performance or facilitating situation awareness. There are both physical capabilities and limitations for the display and the operators within the C2 environment that effect how well information on the shared display is perceived. Basic perceptual issues such as the location of the display with respect to the user and the user's viewing distance are important logistical design considerations. Color measurement issues, including color reproduction capabilities of the display, as well as contrast and illumination, have to be taken into account when choosing a display system. The section will include a review of current guidelines and common display measurements associated with each issue.

3.1 **Location – viewing distance and viewing angle**.

Where the shared display is located in the C2 environment will effect how the display is perceived by the operator. The location of the shared display will constrain both viewing distance and angle and should be a principal consideration in the design. (Alvarez & Jedrysik, 2006). A large shared display in a C2 center is designed to serve a large number of co-located users. But co-located does imply the users will have the same perspective with respect to the shared display. Not all of these users can be seated directly in front of or at an optimum distance from the shared display. Where to situate the C2 personnel is of utmost important; users may be at a fixed location, moving around, or be required to change location (and hence perspective) during an exercise. Conducting measures to assess the visibility of the data presented should take into account three main considerations: operator head rotation, viewing angle, and visual acuity.

Eye Rotation Only
- Optimum: 15° left to right
- Maximum: 35° left to right
- Optimum: parallel and down 30°
- Maximum: 25° above parallel; 35° below parallel

Head Rotation Only
- Optimum: straight ahead
- Maximum: 60° left to right
- Maximum: 50° above and below parallel

Eye and Head Rotation
- Optimum: 15° left to right
- Maximum 95° left to right
- Optimum: parallel and down 30°
- Maximum: 75° above parallel

Table 1. Optimum and maximum eye and head rotation guidelines (in degrees). Da-Lite (1998)

C2 personnel need to be comfortable with both their individual workstation display and interacting with the shared display. Repeated movements beyond a comfortable range of motion can induce stain and fatigue (Ebben, in Da-Lite, 1998). Guidelines for eye and head rotation apply to both the individual workstation displays and shared displays. Shown in Table 1., Joy M. Ebben, Ph.D., CPE (MIL-STD-1472D in Da-Lite, 1998) has outlined easy-to-follow guidelines for optimum eye and head rotation. These guidelines can be used in conjunction with viewing angle and distance measurements to determine the optimal placement of C2 personnel. Be aware, however, while the best place to sit in front of a display is directly in front of it, "directly in front of" a display is ambiguous without taking into account the distance from the display screen. Users closest to the screen will have the wider field of view, and hence require the greatest head rotation and range of motion. User father away may have difficulty with character and symbology size.

The farther away from the display a user is seated, the larger the character and symbology on the display will have to be. Both display resolution and physical size of the shared display will play a role in determining how much information can be presented. The formulas shown in Figure 4. show the character height required for legibility is a function of visual angle and viewing distance, where visual angle is the angle subtended by the character on the pupil and viewing distance is the distance between the observer and the viewed character (Dugger & Barley, 1999). For example, if an shared display user is expected to read the information displayed on a screen, the height of all lowercase characters must subtend *at least* 10 minutes of arc on that viewer's retina. A less rigorous way of saying that is to state that there must be ¼ inch of lowercase character height for every seven feet on-axis viewing distance (Da-Lite, 1998). Besides physical strain and fatigue, it is also important to understand that larger viewing angles can distort and decrease readability, color, and contrast of the shared display.

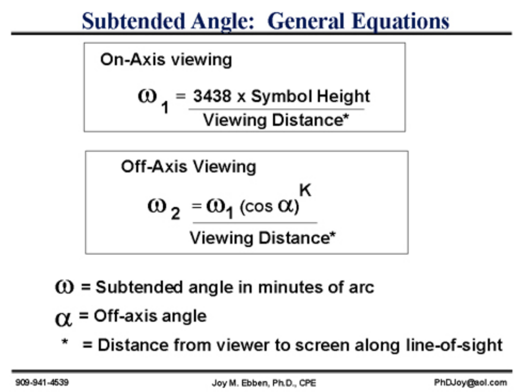

Figure 4. General equations for determining subtended angle.

3.2 Common Display Measurements

Dictated by large display technology currently available, there are three main categories of shared display types: front or rear projection, LCD, or plasma. Each shared display will have their own specific properties pertaining to color, contrast, and screen illumination. Display and measurement equipment set up is critical to any display evaluation. All measurements should be conducted in accordance with applicable military standards and the Video Electronics Standards Association (VESA) display measurement standards. The calibration guidelines and set up procedures are set forth in the VESA Flat Panel Display Measurements Standard, Version 2.0 Publication. In house calibration facilities assure that all measurements are traceable to National Institute of Standards and technology (NIST) standards (Aleva & Meyer, 2003).

While the selection of measurements to be performed on any display will depend on where and how the display is intended to be used, there are a number of measurements which are applicable to almost any display. These include:

- Viewing Angle Effects upon Luminance, Contrast and Color
- Display Color Gamut & Color Coordinates
- Display Luminance Range and Contrast Ratio
- Uniformity of color and luminance
- Ambient Illumination Effects upon Contrast
- Readability

- Power Consumption

3.2.1 Viewing Angle Effects upon Luminance, Contrast and Color

For some displays, contrast will decrease significantly with increased viewing angle. Changes in color may also occur with increased viewing angle. Viewing angle measurements are made to assess what happens when a display is viewed at angles other than the standard straight on perpendicular viewing condition. The same area of the display is measured, while the angle between the measuring device and the display is changed. Typically, the center of the display is measured. Either the display or the measuring device is rotated and repositioned to assure that the same area of the screen is being measured. It is important to measure the same area of the display to assure that spatial inhomogeneity does not contaminate the measurements. White luminance, black luminance and chromaticity coordinates are measured to assess the changes in luminance, contrast ratio or color that may come about as an effect of viewing angle. Viewing angles of +/- 30 degrees horizontal and +/- 15 degrees vertical are generally measured as a check of a manufacturer's viewing angle performance specification; however the selection of what viewing angle to assess can be driven by a particular application (Aleva & Meyer, 2003).

3.2.2 Display Color Gamut & Color Coordinates

The color gamut of a display is dependent on display type (projection, LCD, plasma) and describes in CIE space the range of colors that the display can produce. Three color measurements are necessary to determine a display's gamut. Red is measured at maximum output with Green and Blue set to zero. That gives the triangle vertex in the red in Figure 5. Then Green is measured at maximum output with Red and Blue set to zero. That gives the triangle vertex in the green. Finally, Blue is measured at maximum output with Red and Green set to zero. That gives the triangle vertex in the blue. Straight lines are drawn between vertices (Green, Red), (Green, Blue) and (Blue, Red) to form the triangle that defines the display color gamut (Aleva & Meyer, 2003). Figure 5. illustrates the result of a gamut measurement for the human eye, an LCD display, and a projection display. The LCD monitor can produce only the range of colors depicted by the black triangle. A typical projection display has an even smaller color gamut, depicted by the white triangle.

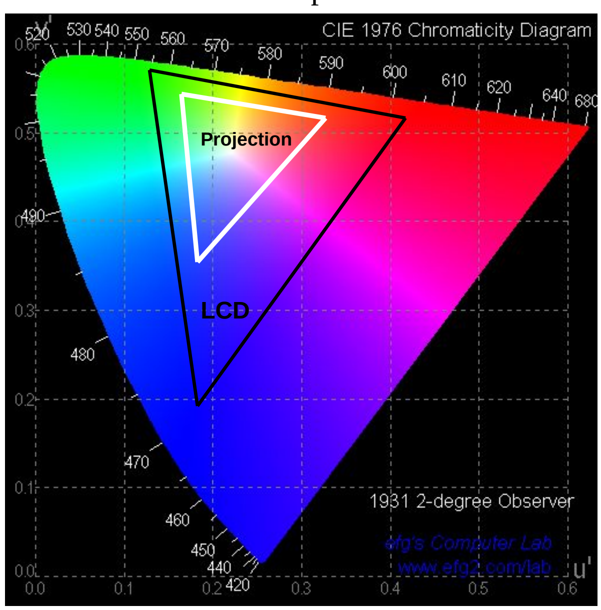

Figure 5. Full spectrum of color visible to the human eye. The black triangle represents the color gamut for an LCD display; the white triangle represents the color gamut for a projection display.

3.2.3 Display Luminance Range and Contrast Ratio

The difference between the luminance of full screen white and that of full screen black gives us the luminance range of the display. This is important if the display is to be used in both day and nighttime conditions. The luminance range also limits the number of discriminable gray shades that the display can produce. This is particularly important for display of continuous tone imagery. Display contrast is important for legibility, particularly of high spatial frequency information such as alphanumerics (Aleva & Meyer, 2003).

Display luminance range and contrast ratio are determined by measuring the luminance of full screen white and full screen black. These two measurements are typically made in the center of the display. The units are typically expressed in candelas per meter squared (cd/m^2). The full screen white measurement requires maximum output from each of the primary display elements, Red, Green and Blue. For a display system with 8 bit color depth the inputs would be: red = 255, green = 255, blue = 255. For systems with more color depth the resulting inputs would be increased accordingly to the maximum value possible. Black is accomplished by setting the Red, Green and Blue to 0,0,0 . The measurement of the black full screen is particularly susceptible to the effects of ambient lighting and room reflections. The full screen white and black luminance values are also used to calculate the Contrast Ratio of the Full Screen. This contrast ratio is expressed mathematically by the equation: $C = L_W / L_B$ where C is the contrast ratio, L_W is the luminance of the full screen white measurement and L_B is the luminance of the full screen black measurement.

3.2.4 Uniformity of color and luminance

It is also very important that the display format employs color or brightness coding. A red symbol should look the same no matter where on the display it appears. Uniformity of color and luminance refers to the variability that exists across the area of a full-screen display when, in theory, different areas of the display should have identical color and luminance characteristics. Measurements are made at specific points on the full screen white display to determine how much luminance and color variation is present in a full screen white display. The display format shown in Figure 5 is used as an alignment guide. Typically, either five (four corners and center) or nine (four corners, center, and midpoint of top, bottom and each side of the display) points are measured. The deviations for luminance are reported as a percentage difference from the maximum white measured. Color differences are reported in terms of u’ v’ differences. The same procedure is followed for each of the red, green, and blue display primaries (Aleva & Meyer, 2003).

Full screen black is measured at the same points, thus giving not only the uniformity of the black screen but also enabling us to compute contrast ratio at each point and evaluate the uniformity of contrast ratio.

3.2.5 Ambient Illumination Effects upon Contrast

A C2 environment is typically a large, open space with higher-than-normal ceilings with variety of general and task lighting configurations. Ambient illumination, or general non-task lighting, is addressed by simply measuring display contrast in the same lighting environment in which the display will be used. Ambient illumination which strikes the surface of the display may be reflected back to the viewer’s eye, thus reducing the perceived contrast of the display (Aleva &

Meyer, 2003). Projection displays are more sensitive to ambient illumination and usually perform better when ambient room lighting is set to a low level.

3.2.6 Readability

If the display luminance is not high enough and the display contrast is too low, the images on the display will not be legible, at least no rapidly legible. The human eye adjusts its aperture (pupil) size depending on the ambient lighting, and can restrict the amount of light from a display. The evaluation of a display to determine its hi-ambient legibility involves evaluating how well it maintain good contrast in lighting conditions typical for where the display will be used.

3.2.7 Power Consumption

Power consumption measurements should be made for the worst case, where the display is adjusted in a manner that the maximum possible power consumption occurs. In cases where this is atypical and where typical settings are available and achievable, power consumption measurement can be made at those settings or conditions.

Listed here were several of the more important perceptual issues to consider when implementing a large shared display, but this is not an exhaustive list. There are several other perceptual issues relevant to contrast and display capabilities, including gray scale and display gamma, shadowing, checkerboard contrast, and response time. A thorough review of the display location, display type, command center configuration including personnel location, viewing distance and angles, should all be taken into account when implementing a large shared display.

4. COGNITIVE ISSUES – "Can I use it?"

The following sections outline some of the important cognitive issues associated with large shared displays. As we mentioned earlier, there is not a lot of conclusive research in these areas, especially with respect to the domain-specific C2 environment. However, we have included some noteworthy research that may be generalizable to strategic, operational, and tactical command center situations. The shared display cognitive issues include:

- Situation Awareness
- Cognitive Task Analysis
    - Task Definition
    - Task Support
- Data Visualization
- Information Sharing
- Display Control

4.1 Situation Awareness (SA)

All of the issues listed under Cognitive Task Analysis are independent concerns for the C2 environment, but they all share a common goal – situation awareness (SA). Endsley (1988) defined SA as a knowledge-based understanding of an environment and provided a three-level description: 1) the perception of elements in a situation; 2) the comprehending of what those elements mean and; 3) the use of that understanding to project future states. Smallman, Oonk, & Moore, (2000). conducted structured interviews with JOC command elements at the Global 2000 War games to ascertain their needs for a shared display to facilitate SA. It was agreed that rapid, shared SA was a high priority.

No one understands exactly what situation awareness is, especially at the group level, but Mynatt et al. (2003) have proposed several network applications to help facilitate SA. Most applicable to the C2 environment are what they term Collaboration Space and Active Portrait. Collaboration Space is an interactive application that provides a platform for individuals to request assistance. A user enters information about the problem or request into the interface, and the interface then allows other individuals to sequentially create and edit the original communication. The continuous, and trackable, communication threads can help to alert many users at once and also reduce mental workload. Another proposed application is Active Portrait. This Active Portrait is a text and graphic application that uses icons to illustrate the individuals in the C2 center, shown in plan view on either a individual or shared display. Icons represent individuals; when the icons are activated, current task and status are displayed.

But does a shared display facilitate SA in the C2 environment? The answer is maybe. Emery et al. (KI) conducted a study comparing shared displays to smaller, desktop displays for achieving SA and reducing mental workload. Their study found that during a simulated C2 exercise at the Joint Force Air Component Commander’s Headquarters (JFAC HQ), there was no significant difference between the displays when participants were measured using the NASA TLX and SART, a situation awareness measure. However, in an assessment of shared displays used over a three-year period at UK JFAC HQ, Emery, L., Catchpole, K., Macklin, C., Dudfield, H., & Myers, E. (2001) reported subjective data indicating that users subjectively reported strong support and preference for large shared displays, citing increased SA and decision support. It may be important to delve further into findings such as these. Was there a problem with the display design than hindered task performance? Is there something inherent in the subjective measure

Of course, the questions of “what is SA?” and “how do I know I have SA” have yet to be answered. A large shared display will only facilitate SA if it has the right information at the right time in an easily readable and understandable format. In order to determine what information would be beneficial on a shared display, the usefulness of any application designed to facilitate SA, or to address any other cognitive issue in the C2 environment, research psychologists use an analysis tool called a cognitive task analysis, or CTA.

4.2 Cognitive Task Analysis

At AFRL, we use cognitive task analysis (CTA) to understand the tasks to be performed and what information is needed as well as the information source and how the information is shared. This is a normative approach to work analysis and the emphasis would be on identifying how operators should use and interact with the shared display for facilitate task performance (Vicente, 1999).

CTA is a set of methods and tools for understanding the mental processes involved in task performance (Klinger & Hahn, 2003). These mental processes cannot be understood simply by observing behavior, particularly if the tasks being performed are complex and require organizing of information and understanding its meaning. The CTA focuses on collaboration requirements within individual cells/teams as well as coordination/synchronization between cells/teams. The CTA documents cell/team functions and tasks, information and decision requirements and flow of information within and between cells/teams. Format and interpretation of information are examined as well as strategies and timing of task performance. Therefore, the information obtained in a CTA is elicited from subject matter experts (SMEs) through in-depth interviews as well as observation. These SMEs will be persons with current or recent experience in the positions of interest. In the C2 environment, CTA would help identify and clarify what individual or team task goals should be, how they will be supported by the display, and also how these goals should be achieved.

4.2.1 Task Support and Task Definition

What kinds of task need to be supported by the shared display? The specific answer to this question can only be determined by conducting a CTA. To design an efficient shared display that supports task performance, C2 command must have a full understanding of all the tasks that require display support. But it is also important to differentiate between different tasks types in the C2 environment. There are three types of tasks: individual, collaborative, or synchronic.

C2 personnel perform individual tasks on a daily basis. These can include submitting reports, handling administrative responsibilities, or monitoring system status. The distinction is individual tasks do not require information or interaction directly from or with other C2 personnel. Large displays can be designed to provide individuals access to or data to facilitate task performance.

Many C2 task require more than one personnel unit to accomplish. Accomplishing these tasks may require small co-located group collaboration or may require disparately located individuals. The C2 task may be collaborative, with individuals or teams pulling together many pieces of the data to achieve a task goal. One team may need information about weather, another team may need information about enemy location. Both pieces of information are needed to complete the task, and displaying useful information for multiple users on a shared display may increase task performance, reducing error and task performance time.

Another type of task is a synchronic task. A synchronic task is collaborative task with temporal constraints. The information one individual or team needs must be received simultaneously with information another individual or team needs to meet the task goal. In this situation, it would be important to present information on the shared display in a timely fashion in order to facilitate task performance.

4.3 Data Visualization

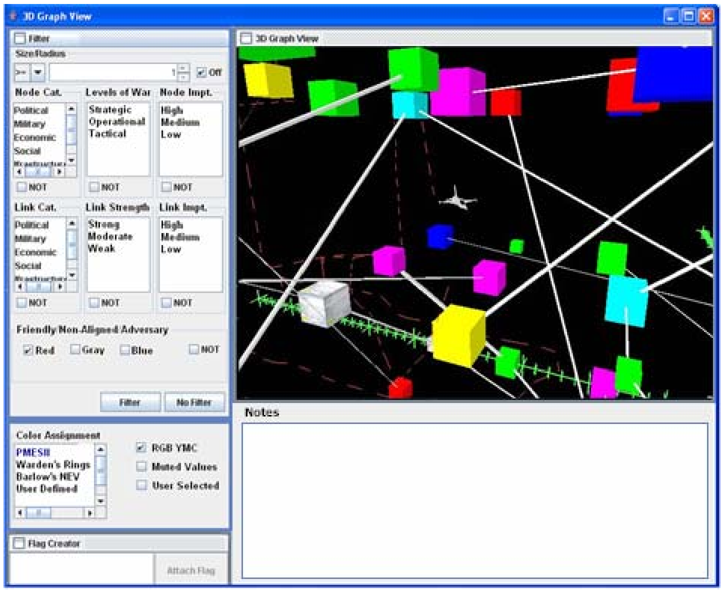

Figure 6. An example of 3D graphics represented on a 2D surface.

The issue of how the data will be presented on the shared display is very domain-specific. Will the applications be 2D, 3D, or a combination? Will the display show graphics, low-level or high-level data?

Polys et al. (2005) have shown that embedded-in or linked-to information may be more navigable and understandable if the display contains 3D visualization software, such as virtual space or 3D object display. They have designed a Viewport Space application to facilitate data visualization and recent studies show improved task performance. …

SIDEview is another application for data visualization. (Mulgund et al., 2005). …

Fisheye techniques (Furnas) ….

4.4 Information Sharing

The sharing of information between individual workstations and a shared display is a vital function in the C2 environment. Mulgund, Travis, Standard, Means, & Burgman (2005) provide a concise overview of the structure both of the shared display and information contained therein. They separate communication interaction into two categories: “pushing” information from an individual workstation to the shared display, or “pulling” information from the shared display to the individual workstation. The pushing of information makes it possible to quickly distribute valuable information, provided other individual workstation are alerted to the push. Pulling information can allow the individual workstation to then drill-down into the high-level data provided on the shared display.

An important question being addressed by researchers is how best to share data and information within C2. The JEFX 04 exercises showed that using individual workstations as repeaters of the shared display was no an efficient use of information space (Darling & Means, 2005), information sharing, or task performance support.

For non-repeating display relationships, Myers, et al. (2001) have developed an interactive style of sharing data. Semantic “snarfing” uses a laser or other pointing device to identify a relevant area of interest on the Shared display (or individual workstation display). Once identified, the data area can be copied directly to the other display. Biehl & Bailey (2004) address the issue of collaborative information sharing with a system called ARIS, or Application Relocation in an Interactive Space. Used with *running* applications, ARIS organizes the physical workspace (the AOC) using an iconic map of the space. ARIS users can relocate applications among screens without being physically close to or physically moving among them, allowing shared information to be located on as few or many displays as deemed appropriate.

Another means of information sharing within the C2 environment is the use of *handhelds*. So ubiquitous today, most people have some idea about interacting with a small, electronic data device. Wireless and mobile, this type of communication network allows the user to interact with the shared display without having to use connected peripherals, eliminating workstation dependence. Myers et al. (2003) studied the use of handhelds (specifically PDAs) as a data sharing “middleman” for larger data networks. The PDAs were shown to be a successful way of moving information from a shared display to an individual workstation. Their studies also showed using PDAs in this fashion resulted in 1) reduced task performance time and, 2) one-half the errors compared to using the display manufacturers remote control device.

Deciding how that information on the shared display will be accessed has implications for the entire C2 center. Will the interaction be remote, using voice recognition software, laser pointers, PDAs, or other wireless devices? Constraints such as shared display location and size will influence these decisions, as well as security issues pertaining to wireless access. Reported multi-users issues include system configurations that cannot recognize simultaneous input from users, and transparent access problems (Alvarez et al., 2006; Jedrysik, Moore, Brykowytch, & Sweed). However, Jedrysik et al. reports a promising speech recognition software called HARK from BBN Systems and Technologies that is speaker independent. This means any user can immediately interact via voice without having to train the system for his or her voice.

4.5 Display Control

Another important issue is the control of data input to the shared display. Some systems allows for multiple users to access the display simultaneously. Others have been configured for automatic updates and information uploads. Research suggests that multiple person interaction of a large shared display is cognitively demanding on the entire team of users. It may be more efficient and effective for individuals or teams to be responsible for the information presented on the shared display. (Bindle, 2005).

According to focus groups conducted by Dugger et al. (1999) at the Integrated Command Environment (ICE) lab at the Naval Surface Warfare Center Dahlgren Division, several general guidelines for shared display control emerged: control of the display should be automated to reduce operator error, a team leader should have discretionary capabilities to override the automation, the team leader should notify other members when an override has been initiated, and the team should be able to create and implement pre-sets to the system.

Some command centers use an *anchor desk* to supervise the information flow through the center. This includes not only the shared display, but a connection with individual workstation. According to a CTA done at the Global 2000 War Game by Smallman et al. (2001), anchor desks could be used to disseminate briefs, risk assessment information, communication status, weather information, and asset allocation information. Their study suggests that if there are changes made to the shared display, there is a need for an alerting mechanism between the anchor desk and individual workstations.

5. ARFL/HECV RESEARCH

The researchers at Air Force Research Laboratories/Human Effectiveness Directorate – Cognitive Visualization are looking at several research areas with respect to large shared displays, including change awareness, situation awareness, data visualization, and the tailored COP.

5.1 Change awareness

The concept of shared display change awareness is relatively unstudied in the C2 environment. But to achieve SA, shared display users must be quickly made aware of changes in information and situation status. In a busy C2 environment, what is the best way to support the recognition of and attendance to important or relevant data changes on the shared display? How the user is notified of relevant changes is an important consideration. Is the alert visual, auditory, or tactile? We are currently designing studies to address some of the issues to determine what kinds of alerts to use with different groups of users, where to place or use the alerts, and if alerts types are dependent on activity levels in the C2 environment.

5.2 Situation awareness

How is situation awareness in the C2 environment defined? Does the shared display facilitate SA? Mentioned earlier, Emery et al. (KI) conducted a study comparing shared displays to smaller, desktop displays for achieving SA and reducing mental workload. While there were no differences found in the objectives measure of the NASA TLX and the SART, subjective measures indicated the display was valuable to the operation. The reasons for the differences between the objective and subjective measures are no known, but they may be related to the design of the display, group motivation variables that could not be measured with the NASA TLX and SART, or some other variable(s) yet to be recognized.

5.3 Data Visualization & the Tailored COP

An important part of C2 display is the Common Operating Picture (COP). While most users agree that a COP is needed, there is little agreement as to what information should be included in the COP, how the information may be tailored for strategic versus operational versus tactical levels of warfare, or to the needs of specific users. Visualization is one of five technologies identified as required for the C2 of the future. This is envisioned to include advanced 3D and 4D information displays, total integration of sound and visualization, and virtual reality technologies.

The current COP in the Combined Air Operations Center – Nellis AFB (CAOC-N) usually displays a CADRG (compressed arc digital raster graphic) map of the area of interest with track overlays of hostile, friendly, and unknown. Although there are eight large projection displays in the Combat Ops room, the same COP is generally repeated on four displays. This COP is cluttered, difficult to read, and not really useful. The purpose of our current research is to explore tailoring the COP to groups of users within the CAOC-N.

Using CTA tools and techniques, we will be addressing questions such as:

- What information needs to be included in the COP?
- What information needs to be available to all users and what information can be tailored to specific users?
- What visualization prototypes would be useful in both a CAOC/C2 environment and on C2 aircraft?
- What are the differences between strategic, operational, and tactical applications?

SUMMARY

A primary goal of large shared displays in the C2 environment is to support task performance and facilitate SA. Perceptual and cognitive issues need to be studied and guidelines provided to maximize the effectiveness of the human computer interaction (HCI). It is interesting to note in 1986, McNeese & Brown published a report discussing variables of concern for large group displays. Included in this report were perceptual design issues including display format, information density, and information representation. They also outlined cognitive variables of concern, including task complexity, display allocation, and mental workload.

Today, researchers have a good understanding of the perceptual issues regarding large display. Issues of display location, viewing angle and distance of the user, and color measurement issues are solvable design problems. However, implementing a large display system without addressing these issues can cause difficulty in perceiving and reading the data presented and lead to under-utilization of the shared display.

The cognitive issues, on the other hand, have yet to yield practical, generalizable guidelines. Facilitating SA and supporting task performance are difficult research questions. Even the purpose of a shared display in a C2 environment is ambiguous. Current shared displays are usually designed to provide a top-level composite view of the air tasking order (ATO) plan and execution. Bindl (2005) suggests that current versions of COPs are flawed by being subject to "varied interpretations" based on the perspectives of the observers, and the further away the observer is from the process of developing the COP, the greater chance the observer will have of misinterpretation. The convergence of data from many disparate sources in current COPs can result in a overlapping and redundant data provided only to upper level command units. Again, the large display, including the COP, should be a foundation for common understanding and SA, and current versions are generally viewed as having little or no value.

The researchers here at AFRL have spent years studying the perceptual issues associated with human computer interaction (HCI). We are looking forward to studying some of the cognitive issues and providing information and understanding for C2 environments.

REFERENCES

Aleva, D. L., & Meyer, F. M. (2003). AFRL battlespace visualization branch display characterization facility. *Proceedings of SPIE 2003.*

Alvarez, R.C., Jedrysik, P.A., (2006). Enhanced interactive Data Wall: Display architecture for data fusion and collaboration in C2 environments, *Proceedings of SPIE 2006, 6225*, 62250N.

Biehl, J.T. & Bailey, B.P. (2004). ARIS: An interface for application relocation in an interactive space. *In Proceedings of Graphics Interface 2004*, pp. 107-116.

Bindl, P.J. (2005). Does a common operating picture result in common understanding of the battlespace? *Technical Reports,* Report XBNWC/JMO.

Darling, E., Means, C.D. (2005). A methodology for unobtrusively determining the usage of C2 data walls. *10th Annual Command and Control Research and Technology Symposium: The Future of C2.*

Dugger, M., & Barley, D. (1999). Guidelines for the implementation of large screen displays in an integrated command environment.

Emery, L., Catchpole, K., Macklin, C., Dudfield, H., & Myers, E. (2001). Big is better? Empirical results of an assessment of command teams with large screen displays. Defence Evaluation and Research Agency for HMSO. British Crown Publishing.

Da-Lite Screen Company (September, 1998). Angles Of View. Vol. IV, ©9. http://www.da-lite.com/education/angles_of_view.php?action=details&issueid=17.

Endsley, M. R. (1988). Situation awareness global assessment technique (SAGAT). Proceedings of the National Aerospace and Electronics Conference (NAECON). (New York: IEEE), 789-795.

Furnas, G.W. (1986). Generalized fisheye views: Visualizing complex information spaces. *In Proceedings of Chi'86, ACM Press,* 16-23.

Jedrysik, P.A., Parada, F.E., Stedman, T.A., Zhang, J. (2003). Advanced interactive displays for deployable command and control centers. *Proceedings of SPIE 2003, 5080,* 260-271.

Jedrysik, P.A., Moore, J., Brykowytch, M., & Sweed, R. The interactive datawall.

Klinger, D. W., & Hahn, B. B. (2003). Handbook of team CTA (manual developed under prime contract F41624-97-C6025 from the Human Systems Center, Brooks AFB, Tx). Fairborn, Oh: Klein Associates, Inc.

McNeese, M. D., & Brown, C. E. (1986). Large group displays and team performance: An evaluation and projection of guidelines, research, and technologies. TR: AAMRL-TR-86-035. AD: A255771.

Mulgund, S., Travis, A., Standard, J., Means, C.D., Burgman, A. (2005). Shared user interfaces for dynamic collaboration in network-centric command centers. *10th International Command and Control Research and Technology Symposium: The Future of C2.*

Myers, B.A., Peck, C.H., Nichols, J., Kong, D., & Miller, R. (2001). Interaction at a distance using semantic snarfing. *In Proceedings of Ubiquitous Computing: Third International Conference*, 305.

Mynatt, E. D., Huang, E. M., Voida, S., MacIntyre, B. (2003). “Large displays for knowledge work.” In O’Hara, K., Perry, M., Churchill, E., Russell, D. (Eds.) *Public and Situated Displays*. Kluwer Academic Publishers, 2003, pp 80-102.

Polys, N.F., Kim. S., Bowman, D.A. (2005). Effects of information layout, screen size, And field of view on user performance in information-rich virtual environments. *In Proceedings of ACM VRST’05,* 46-55.

Smallman, H. S., Oonk, H. M., & Moore, R. A. (2001). The knowledge wall for the Global 2000 War Game: Design solutions to match JOC user requirements. SSC San Diego. Technical Report 1860.

Vicente, K. J. (1999). *Cognitive work analysis: Towards safe, productive, and healthy Computer-based work.* Lawrence Erlbaum: New Jersey.