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A Methodology for Unobtrusively Determining the Usage of C2 Data Walls

Human Factors Engineering

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ABSTRACT

A Human Factors Engineering (HFE) analysis was conducted of the Nellis Air Operations Center (NAOC) Data Wall (DW) at the Joint Expeditionary Force Experiment 2004 (JEFX '04) from 2 August 2004 to 3 August 2004 during the main experiment (MainEx). The main purpose of this analysis was to evaluate the usability, readability, and usage of the DW during simulated operations. Additionally, a separate HFE analysis was conducted of the DW at the Department of Homeland Security's Federal Emergency Management Agency Regional Operations Center (FEMA ROC) on 27 July 2004 during the Democratic National Convention. This paper presents a methodology for unobtrusively determining the usage of data walls that was refined during the Democractic National Convention and utilized during JEFX '04, the results of the HFE analysis at JEFX '04, and recommendations for the DW at JEFX '06. Additionally, these design recommendations can be applied to other large shared displays across C2.

INTRODUCTION

This paper describes an analysis that two MITRE Human Factors Engineers (HFEs) conducted of the Data Wall (DW) at the Joint Expeditionary Force Experiment 2004 (JEFX '04) from August 2-3 during the main experiment (MainEx). The purpose of the study was to evaluate the usability, readability, and usage of the DW to develop recommendations for improving the DW for JEFX 2006. Before beginning our analysis at JEFX, the methodology was tested at the Department of Homeland Security's Federal Emergency Management Agency Regional Operations Center (FEMA ROC) on 27 July 2004 for two hours during the Democratic National Convention.

It was imperative at JEFX '04 that our HFE analysis of the DW did not alter the experiment because hundreds of operators were performing coordinated tasks, while controlling live airborne assets. Similarly, it was essential we did not disrupt operations at the FEMA ROC because the personnel needed to adeptly identify and manage any crisis that might arise. Therefore, we could not consider direct measures of situation awareness (SA) that would require freezing the operations at different times to gather feedback. Our methodology consisted of interviews, unobtrusive observations of the personnel both at and away from their workstations, and our own ergonomic and heuristic evaluations.

Related Research

It has been found that DWs should only be included in a command environment when it enhances team performance. For example, DWs would be appropriate in situations where overall system status may help an individual make a better-informed decision regarding his/her specific task. When this is not the case, DWs can actually detract from the individual's performance [1].

Dugger and Barley [1] conducted a focus group with eight naval Subject Matter Experts (SMEs), averaging approximately 16 years of active service, about the benefits of DWs. The SMEs decided the most significant benefit was the ability to gain a shared situation awareness. The general consensus was that decisions to change the content on the DWs should be made by the team leader and should be completed by one of the operators. Another recommendation the participants generated was to save several presets for different situations that may arise.

When designing content for a DW, Somervell and McCrickard [9] developed the following design heuristics for DWs: (i) appropriate color schemes can be used for supporting information understanding, (ii) layout should reflect the information according to its intended use, (iii) judicious use of animation is necessary for effective design, (iv) use text banners only when necessary, (v) show the presence of information, but not the details, (vi) using cyclic displays can be useful, but care must be taken in implementation, (vii) avoid the use of audio, and (viii) eliminate or hide configurability controls.

A study by Roth *et al* [5] determined that DWs can provide the following capabilities: (i) display current system status to multiple team members simultaneously, (ii) provide a walk-up display device for briefing and group-work purposes, (iii) enable team members to see the effects of their actions on the tasks of other operators, (iv) facilitate monitoring of the team by the leader. For each of these capabilities, the DW is providing Situation Awareness (SA).

SA has been defined as a three-step process involving, 1) detecting or perceiving elements in the environment, 2) processing or comprehending the current situation, and 3) acting on the information or projecting the future status of the situation [2]. Endsley's work in team situation awareness (SA) has resulted in the following design principles: (i) build a common picture to support team operations, (ii) avoid display overload in shared displays, (iii) provide needed display flexibility to support shared SA across functions, (iv) support transmission of different comprehension and projections across teams, (v) limit non-standardization of display coding techniques, and (vi) support transmission of SA within positions by making status of elements and states overt.

A human factors study was conducted [6] of the Knowledge Wall (K-Wall) during the 2000 War Game sponsored by the Office of Naval Research. The K-Wall provided integrated information through the use of a stoplight chart (red, yellow, and green status symbols). A representation of the K-Wall is in Figure 1 and a detailed view is shown in Figure 2.

Figure 1. K-Wall at 2000 War Game

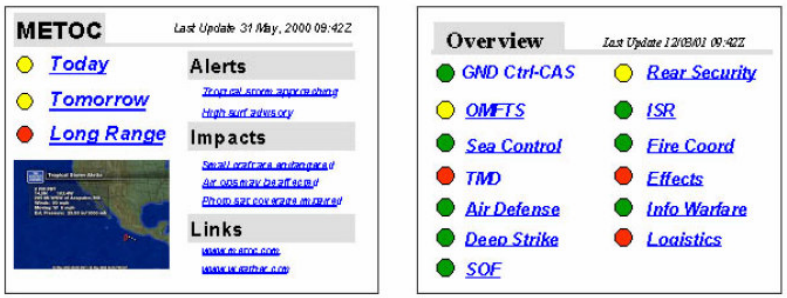

Figure 2. Example of Summary Data shown on K-Wall

It became evident that the K-Wall was providing the participants with SA as the need for the eight-hour briefing cycle lessened until it was eliminated altogether. The following improvements to the K-Wall were deemed necessary by the human factors team: (i) tools to support attention management and change detection, (ii) tools and revised business processes to support improved multi-tiered collaboration, (iii) design layouts to support improved text legibility, (iv) information integration across functional areas, and (v) tools and methods to communicate age and source on the summary pages [6].

DESCRIPTION OF DATA WALLS

The DW at the FEMA ROC consisted of three large screens that took up one of the walls in the room. It displayed a web-based emergency management communications system, which was essentially a scrolling list summarizing the incidents occurring in Boston. There was not a great deal of activity occurring in Boston at the time so the list only changed about once every fifteen minutes. Each of the walls showed a different subset of the incidents. The personnel sat facing the DW. Hanging from the ceiling around the room were plasma displays broadcasting news channels.

The DW on the main ops floor at JEFX '04 consisted of eight screens side-by-side filling the entire length of one of the walls, with the second four screens being a duplicate of the first four. Almost all of the screens on the DW were operators' displays that were mirrored onto the DW. The operators on the main

ops floor sat in rows facing the DW, which displayed weather, target lists, a battlespace picture, and static PowerPoint slides. The information being displayed ranged from briefing slides that never changed to dynamic target lists. The DW configuration only changed twice a day for about an hour at a time during the Distinguished Visitor (DV) tours. During this switch, one of the screens would be divided into four quadrants to show more static PowerPoint slides.

The DW in the Plans & Strategy room consisted of four screens; each was either a PowerPoint slide or a screensaver that had turned on through inactivity. An interesting thing happened in the Plans & Strategy room. Because the operators didn't find the DW sufficient for their needs, the operators purchased four projectors before MainEx so that they could have a small shared display for each of their teams. They found it easier to collaborate using these smaller shared displays than the DW. During MainEx, only two of the four projected workstations were still being used for developing plans. Both were used for building Excel spreadsheets for the Combined Forces Air Component Commander (CFACC) to review. Another interesting transformation occurred in the Plans & Strategy room between earlier spirals of JEFX 04. During Spiral 2, the overhead lights were dim, and the room was oriented to face the DW. During Spiral 3, the overhead lights were on and the room was oriented in rows perpendicular to the DW, with several rows facing each other. Operators stated they'd rather work with the lights on since they were not using the DW. For MainEx, the operators continued to sit perpendicular to the DW. However, the lights were turned down so that it would look more like an AOC for the DV tours.

METHODOLOGY

We surveyed the SA literature and ethnography literature looking for techniques we could use to unobtrusively determine how operators were using the DW. We were unable to find any techniques that met our requirements and we decided on traditional human factors engineering techniques of interviews, observations, and ergonomic and heuristic evaluations.

Interviews

Prior to visiting the FEMA ROC, we prepared a set of interview questions. The initial set of questions were based on the Critical Incident Technique [3] and asked people to recall a particular example, such as:

- Describe a time that the DW assisted you in completing a task.
- Describe a time that the DW distracted you and made it challenging to complete a task.

Three separate FEMA personnel were approached when they seemed in between tasks and asked if they had a few moments to answer questions about the DW. All three agreed and were interviewed. From the quality of information gathered from the three interviews, it was realized that the interview questions could be improved. People seemed unsettled by the questions that asked them

to recall a particular instance. We decided to omit these questions from the quick, informal interviews. A better approach was to ask direct questions about the usefulness of the DW.

The modified interview questions were:

- Are you able to easily read the information on the DW?
- How often do you look at the DW?
- Do you find DW useful for you when completing your work?
- What type of information do you look at on the DW? Do you also have access to that information on your workstation? If so, what causes you to view it on the DW?
- What changes would you make to the DW?

Observations

Because of Roth's study [5] that specified the different ways the DW could be utilized, we hypothesized that the DW would be helpful to operators while at their workstations, upon walking onto the operations floor, and when having standing discussions away from their workstations with other operators. The DW would provide operators at their workstations with a shared awareness of the overall status. When returning to the operations floor, operators could glance at the DW to gain an awareness of how activities had changed since they were last in the room. Operators having standing discussions away from their workstations could use the DW as a common point of reference.

To explore this hypothesis, we observed groups of operators for ten minutes at a time. At the FEMA ROC, we observed the groups of operators by standing right near them. However, the operators were too aware of being observed. Therefore, for the observations at JEFX, we made sure to be less conspicuous. We also watched the DW to notice behaviors of the operators whose workstations were being mirrored on the DW.

Although this is not the ideal method for determining DW usage, it was the best method that did not interfere with operations. If interference was possible, a better method would have been to setup eye tracking equipment with operators in key positions. Another option we considered was to shadow a single operator for a considerable length of time. However, we felt it would be more important to observe a broad sample of users rather than shadow a select few who we suspected used the DW.

Ergonomic and Heuristic Evaluations

The first part of the ergonomic evaluation was to calculate the ideal viewing distance from the DW using the visual angle formula, $\mathbf{va}=\tan^{-1}(\mathbf{h}/\mathbf{d})*3438$, where **h** represents the height of the DW and **d** represents the distance from the DW, and solving for **d** [8].

The second portion of the ergonomic evaluation was a visibility assessment that the human factors engineers conducted by standing in multiple locations

along the wall opposite from the DW and noting what could be discerned on the DW.

The human factors engineers then conducted a heuristic evaluation. For heuristics, the set developed by Somervell and McCrickard [9] for DWs was utilized and we noted the extent to which the DW met each of the heuristics. This set of heuristics was chosen because they seemed the most appropriate for large shared displays in a command and control environment. For example, the third heuristic pertained to the importance of judicious use of animation. Sensory work conducted by Goldstein has demonstrated that, "Movement attracts our attention….Movement in our peripheral vision usually triggers an eye movement that brings the moving object's image onto our foveas so we can see it clearly." This highlights the importance of not putting a lot of animation, such as a Predator video feed, on the DW because it would constantly attract attention. Furthermore, it should be noted that a similar phenomena occurs with cable news channels. They have a lot of movement specifically designed to capture the viewer's attention. Thus, screens of news feeds should also be placed judiciously within the command center.

We did not make any methodological changes to the ergonomic and heuristic evaluation after they were tested at the FEMA ROC.

FINDINGS

Interviews

A few different personnel were interviewed on their opinions of the DW at FEMA. They felt that the DW was useful because they were able to notice in the periphery if a new event scrolled onto the screen. There were not enough events occurring that they wanted the emergency management system to take up screen real estate on their own workstations.

Sixteen operators were interviewed at JEFX. Half of them responded they never looked at the DW. Of the other half, five operators said they occasionally looked at the DW, defined as about once per day. The remaining three operators said they often looked at the DW, defined as more than once an hour.

Table 1. Summary of JEFX Interviews

Explanations of operators who *never* looked at the DW	**Number of responses**
Cannot read most of the information from my seat in the back of the room.	3
The information on the DW is not appropriate for me/for my level.	5
Explanations of operators who *occasionally* looked at the DW	**Number of responses**

Look at what the TCT chief is currently working.	3
Compare app on wall to app on my workstation.	1
When directed to by a superior.	1
Explanations of operators who *often* looked at the DW	**Number of responses**
Sit directly in front of the information of interest and it is easier to glance up at the app then to open it on workstation.	2
My workstation is mirrored on the DW.	1

The five people who said the DW was not intended for them hypothesized who it was intended for. However, they were often incorrect. For example, the Combined Forces Air Component Commander (CFACC) said that the information was not for him, but that it was at the level of the Chief of Combat Ops (CCO). When interviewed, the CCO said the information was not at his level but was useful to the CFACC.

Several people remarked that the PowerPoint 'rotisserie' was the most useful screen on the DW. It is nicknamed a 'rotisserie' because it rotates through slides of rules and instructions. However, the information was static and therefore lost its value once the operators had read through all of the information.

Observations

What people think and report they do is sometimes different from what they actually do. Therefore, it is also important to observe people's behaviors. It was observed at the FEMA ROC that people did occasionally glance at the DW when a new event scrolled onto the screen. This was in agreement with what people reported.

At JEFX, the following observations were made on the main ops floor and pertain to consequences of having a desktop mirrored on the DW:

- It was observed 15 times during the two days of observation that someone's screen would go into ScreenSaver mode from inactivity. It was then witnessed on the DW that the operator would need to enter a password to unlock the workstation.
- When the CAOC level changed to a red condition, it would have to be repeatedly announced over the P.A. system. The status in the 'PowerPoint rotisserie' read yellow and it was not updated to reflect the current situation. This happened 2 times.
- The operators would have to pull pop-ups from the screens being mirrored to their other screens (each workstation had two screens) so that they wouldn't be visible to the ops floor. This occurred 96 times.

- To prevent his team from being misdirected by work-in-progress, the TCT Chief would either enter targets as hidden rows or position the table of targets below the screen so that only part of the table was visible.

The following observations were made of how frequently operators on the main ops floor consulted the DW:

- One HFE stood facing the doorway for fifteen minutes on two different days and two separate times of day and observed 0 people look at the DW upon entering the room to gain SA. It also should be noted that the first screen visible when walking in the door was a blank desktop that was being mirrored on the DW.
- Two HFEs stood in various locations on the floor observing different sections of operators to count how often they looked up at the DW from their seats. The total observation time was 60 minutes. In that time, it was observed 10 times that operators glanced up at the DW. However, it is unknown if they were merely glancing away from their workstations or if they were purposely looking at the DW. It was not observed that operators did anything more than glance at or scan across the DW. For example, it was never witnessed that people would repeatedly look back and forth between their workstations and the DW.
- It was noted over the two days whether operators referred to the DW during the conversations they had standing away from their workstations. Other than the DV tours, when the guide would draw attention to the DW and tell the DVs it was for SA, it was only observed 1 time that a small group of operators referred to the air picture on the DW while in conversation away from their workstations.

Ergonomic Evaluations

Using the visual angle formula, it was calculated that the ideal viewing distance was 19' from the DW. This was equivalent to sitting in the third of five rows from the screens. This is compatible with an informal poll conducted with operators in each of the rows. Unlike the first row that said they sat too close to be able to view the DW or the last row that said they couldn't see the details on the DW, the third row said they could easily read the info on the DW.

Evaluating the DW in terms of the heuristics, we found that it satisfied three of eight heuristics, which can be seen in Table 2.

Table 2. Summary of Heuristic Evaluation

Heuristic	Observation of DW at JEFX
Appropriate color schemes used for supporting information understanding	The DW did **meet** this heuristic because it used green, red, and yellow appropriately to represent status on certain screens and friendly or enemy forces on other screens.

Layout reflected the information according to its intended use	The DW did **not meet** this heuristic because the information on the DW was not designed with operator location in mind. An example of this was the Army BCD Chief saying that the information on the wall in front of him (and the BCD) was not for the Army guys.
Judicious use of animation	The DW did **meet** this heuristic because most of the information on the DW was static screenshots or PowerPoint slides. Also, Predator video was prohibited from the DW, which would have been a distraction to many on the Ops floor.
Use text banners only when necessary	The DW did **not meet** this heuristic because there was a considerable amount of text on the DW and it could not be read from most places in the CAOC.
The presence of information was shown, but not the details	The DW did **not meet** this heuristic because it mirrored individual workstations. It did not roll-up the information to show high-level status information.
Care was taken in the implementation of cyclic displays	The DW did **not meet** this heuristic because it did not provide an indication of where the display was in its cycle and because it continued to cycle through each day even though the information was static.
Use of audio avoided	The DW did **meet** this heuristic because it did not have any auditory capabilities.
Configuration controls removed	The DW did **not meet** this heuristic because it mirrored individual workstations that were being used for storybuilding onto the DW. This resulted in text that was too small to read and too much screen real estate occupied by unnecessary window controls.

CONCLUSIONS

The goal of increasing shared situation awareness is critical for the evolving net-centric enterprise. While the DW can become a useful tool towards achieving this goal, changes in design and usage are required to fully exploit the available technology. By following the recommendations encompassed in this report, engineers can develop and implement a more useful instantiation of the NAOC DW.

Previous research and experimentation have found it is important for DWs to provide high-level summary information as opposed to detailed data. This

cannot be achieved by mirroring an individual workstation onto the DW. The effects of mirroring an individual workstation were seen in the added aggravation to the operators of those workstations having to hide different portions of their screens. The main benefit of mirroring a display is that a team can see what its leader is focused on if the leader's screen is being mirrored. However, we feel that the benefit can be achieved if the user could specify which portions of the screen to broadcast onto the DW through distributed object technologies. A proof of concept has already been achieved through Mulgund's SIDEView (Symbiotic Display Ensemble for Visualization and Interaction) work [7], which demonstrated command center information sharing using network-centric technologies, providing re-creations (formatted for the appropriate display platform) of operator displays.

Recommendations

The following recommendations pertain to the type of information displayed on the DW:

- Continue to not display Predator video, or other information that would attract attention unnecessarily, on the DW.
- Provide activity awareness to show the current state of tasks, check lists, and/or operations. Consider the way the K-Wall displayed high-level stoplight charts at the 2000 War Game. Show the presence of information but not the details.
- Provide summary status information on the first screen visible upon walking through the doorway (as opposed to a blank desktop).

The following recommendations pertain to the way information is displayed on the DW:

- Do not mirror operators' workstations onto the DW. Consider the SIDEView prototype that Mulgund *et al* developed that incorporated web services to publish and subscribe data between individual workstations and the DW.
- Rather than keeping the layout and the content of the DW static except for the brief DV visits, develop presets that can be easily switched on or off depending upon the current situation, for example, downed aircraft, incoming ballistic missile, and high value targets.
- Eliminate or hide configurability/windows controls used for storybuilding.
- Provide smaller, collaborative displays for teams and groups, such as the operators in the Plans & Strategy room.
- Present information graphically with little text to encourage the presentation of high level information, not detailed information. The text that does appear on the DW should be readable by all targeted users.

In addition to developing recommendations for the DW, we learned the methodology of interviews, observations, and ergonomic evaluations was sufficient for achieving a sense of how the DW was used at JEFX '04. To get an accurate assessment of how it was used would have required interfering with the exercise and with the operators. We found it useful to test out the methodology, in addition to learning how the DW is used in a homeland security scenario, at the FEMA ROC to understand how the methodology would be received by the personnel.

The following recommendations are for future HFE studies of large shared displays:

- Develop an alternative display that replaces detailed information resulting from mirroring individual workstations with high-level status information. Conduct a study to compare the usage and usability of the two versions of the DW.
- After conducting a broad survey of usage of the DW, select a few operators (both ones who claim to use the DW and ones who claim not to use it) to shadow to gain a more comprehensive understanding of their usage.

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ACRONYMS

AOC	Air Operations Center
BCD	Battlefield Coordination Detachment
CAOC	Combined Air Operations Center
CCO	Chief of Combat Ops
CFACC	Combined Forces Air Component Commander
DV	Distinguished Visitor
DW	Data Wall
FEMA	Federal Emergency Management Agency
HFE	Human Factors Engineering
JEFX	Joint Expeditionary Force Experiment
NAOC	Nellis Air Operations Center
ROC	Regional Operations Center
SA	Situation Awareness
SIDEView	Symbiotic Display Ensemble for Visualization and Interaction
SME	Subject Matter Expert
TCT	Time Critical Targeting