Controller Centered HMI:
Lessons Learned on the Design of HMI for Next Generation ATC Systems
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Lessons Learned Designing an Alternative CHI for En Route Air Traffic Control*

Maria C. Picardi
M.I.T. Lincoln Laboratory
Lexington, MA 02173-9108
(781) 981-4391/(781) 981-3220/MPICARDI@ll.mit.edu

Abstract

MIT Lincoln Laboratory is supporting the FAA-sponsored effort to design an operationally suitable Computer Human Interface (CHI) for the recently upgraded En Route Air Traffic Control Centers. All centers will soon receive new control consoles with state-of-the-art 20" square (2K by 2K resolution) color displays (currently operating in Seattle as of January 1999). The future CHI is being modeled on Eurocontrol's Operational Display and Input Development (ODID) CHI, as requested by active controllers in the US. The ODID-like CHI, with its minimal information display and color coded guidance, provides increased efficiency and productivity through employment of a modern graphical user interface. Lessons learned during the on-going design process, including research of look and feel issues in conjunction with data analysis from controller-in-the-loop testing of a prototype ODID-like CHI will be discussed.

The Laboratory plans to model the alternative ODID-like CHI on the best of the European ODID, Denmark Sweden Interface (DSI) and EATCHIP CHI features, while cognizant of the FAA's DSR capabilities and limitations to support an improved user interface. Human factors issues need resolution to provide a consistent look and feel across the Free Flight Phase 1 products and platforms, the Center TRACON Automation System (CTAS) and the User Request Evaluation Tool (URET). MIT Lincoln Laboratory has built a CHI Requirements Engineering Model (CREM) to support controller-in-the-loop testing of the ODID-like CHI, validate CHI requirements and determine applicable standards for the design of an integrated CHI. The CREM provides a means to assess various CHI alternatives and the capability to iterate options with controller teams to address user concerns. Lessons learned from the ODID-like CHI specification process will also be shared.

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Introduction

MIT Lincoln Laboratory is supporting the FAA in conducting human factors research and testing activities to facilitate the introduction of Eurocontrol's advanced user interface to FAA's Display System Replacement (DSR) consoles and Free Flight Phase 1 (FFP1) products. This paper documents the Laboratory's current research into an evolutionary ODID-like alternative CHI introduction for en route air traffic control (ATC). User interface display concepts designed to optimize human performance, including controller response times, workload and situational awareness while using an advanced alternative CHI are being investigated using a new CHI requirements engineering model (CREM) developed by the Laboratory. The CREM is being used to rapidly prototype and test iterations of the ODID-like CHI design to validate alternatives with data as needed.

As part of an ongoing collaboration between the FAA and Eurocontrol, information will be exchanged concerning applied research on the Human Machine Interface (HMI) / Computer Human Interface (CHI) for Air Traffic Management (ATM) systems. The work reported here is a beginning in the search for resolutions to all front-of-the-glass considerations such as minimal information display, direct manipulation with menus and buttons, the use of color, windowing techniques, and information layering for use in decision support tools for both advanced ATC and ATM.

Challenge: Alternative CHI for DSR

All of the En Route Air Route Traffic Control Centers (ARTCCs) will soon receive new control consoles with state-of-the-art 20" square (2K by 2K resolution) color displays to be deployed by the FAA's Display System Replacement (DSR) program. DSR became operational in the Seattle center as of January 1999. The DSR CHI is essentially the same as the existing Plan View Display (PVD) CHI currently in use by Radar controllers at the majority of ARTCCs. Two noteworthy differences are the use of color and electronic keys instead of knobs and dials. A new display monitor (currently 15 inches diagonal) is introduced in the D position of the DSR console to aid the controller working with flight information and related data while assisting the radar controller. However, the use of paper flight strips remains as in the existing M-1 console.

Figure 1. Existing M-1 console with PVD

Figure 2. New DSR console with color display

The design challenge, which motivates research into an alternative CHI for DSR, is depicted in Figures 1 through 3. Figures 1 and 2 depict the R and D positions for the existing and new en route control consoles, respectively. An expanded view of the R position main situation, color display is depicted in Figure 3. The new DSR color set [1] consists of yellow data blocks on a blue background with different patterned filled hues of blue for weather. The DSR radar display also can be used to view a selectable number of windows for accessing the electronic keys and viewing textual lists. The DSR data blocks maintain the same display format as on the PVD and are not interactive or color-coded as in the alternative CHI. the Eurocontrol-based CHI displays flight plan information only electronically upon data block selection.

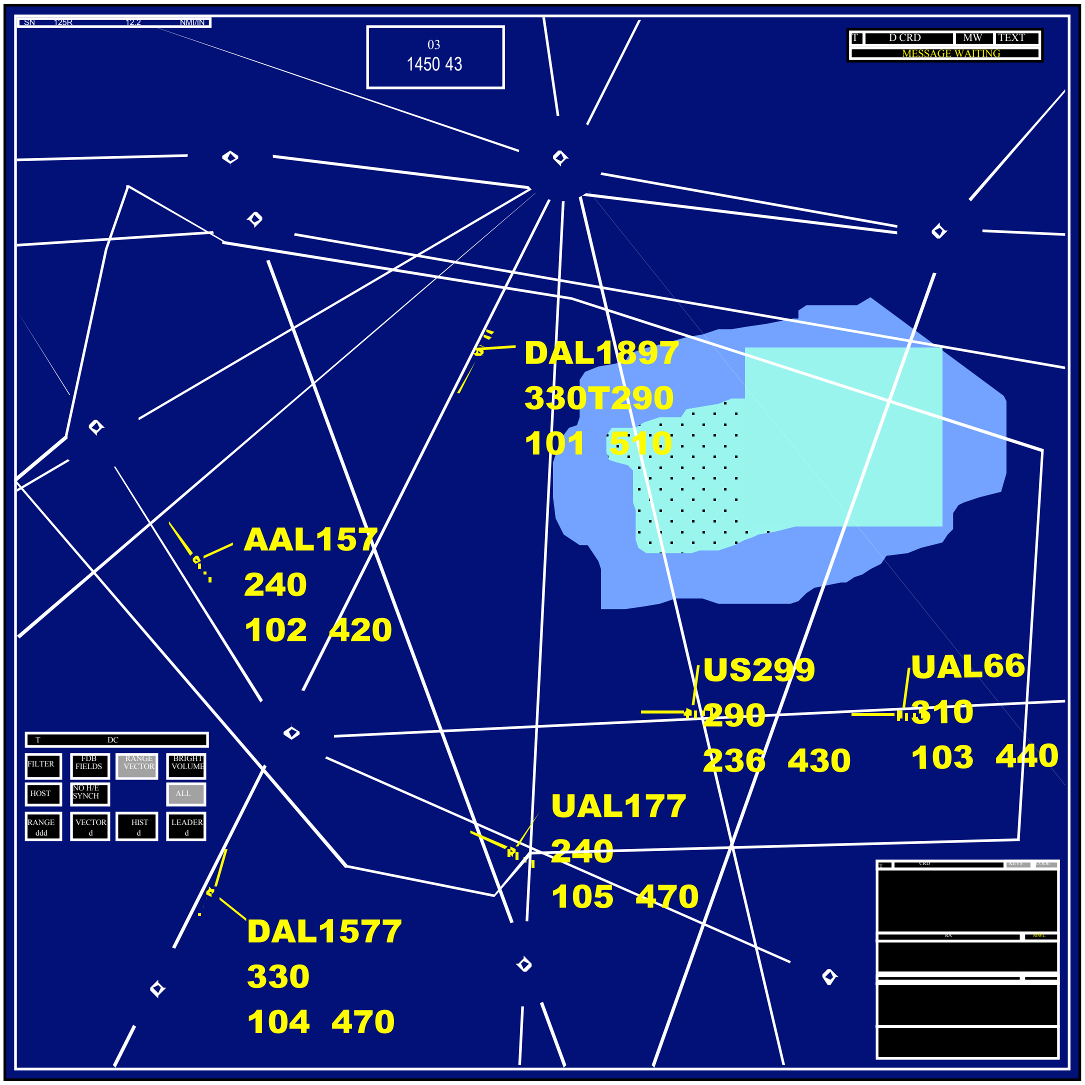

Figure 3. New DSR 20" square color display

CHI Design Basis

The alternative CHI for the future is being modeled on Eurocontrol's Operational Display and Input Development (ODID) CHI, as requested by active controllers in the US. The ODID-like CHI, with its minimal information display and color coded guidance, provides increased efficiency and productivity through employment of a modern graphical user interface. Following the positive outcome from Eurocontrol's controller simulations conducted in 1996, an ODID IV - PVD baseline comparison was conducted by the FAA. ODID has since been updated by the EATCHIP program's design principles including: display only minimal information, keep it simple, display multiple interactive menus pulled down from data block fields, default cursor placement within menu on the expected entry (see Figure 4 showing an altitude selection entry for the next cleared flight level), minimize keyboard use, display multiple interactive lists (see Figure 5 showing a Message In list used for system assisted co-ordination among controllers), reduce reliance on paper flight strips and employ color coded guidance.

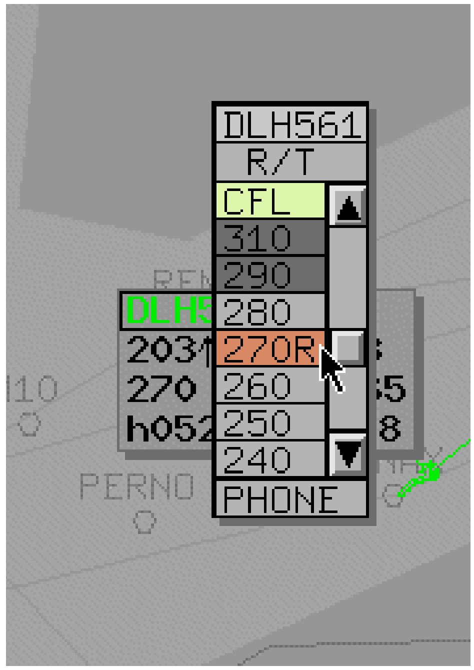

Figure 4. Pull down menu

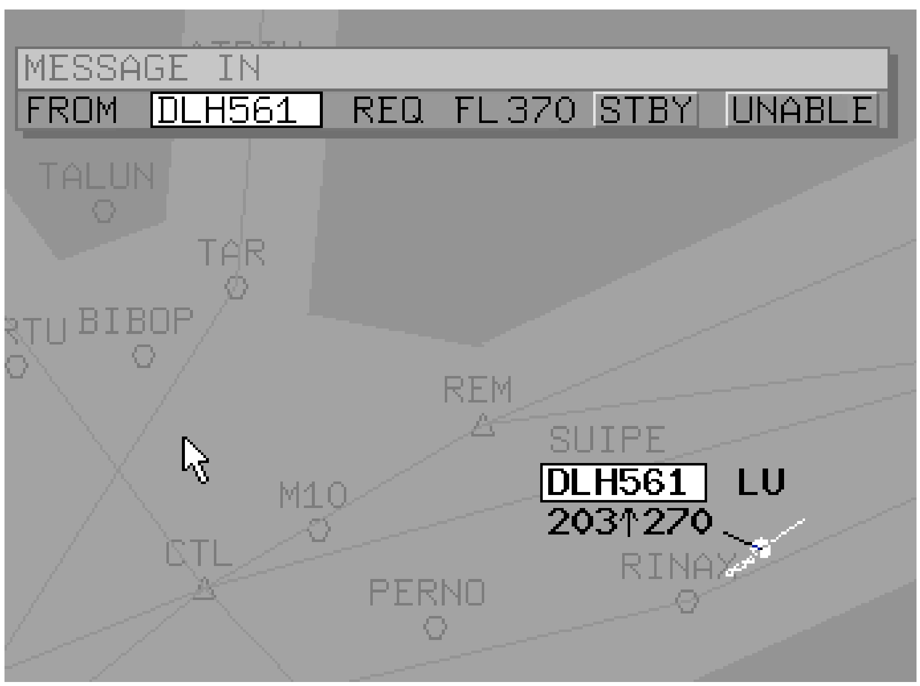

Figure 5. Message In list

Lessons Learned

CHI Design Approach

In exploiting modern graphical capabilities for en route air traffic control using the new DSR platform, the Laboratory has followed a systematic approach over the last two years working with the FAA research management and operational personnel. First, ideas were generated for an integrated operational concept based on a survey of existing concepts including the Conflict Probe Operational Concept [2] and the Con Ops for 2005 [3]. Once the new operational concept was briefed to and accepted by representatives of the air traffic control community, the focus shifted to assessing operational suitability of an alternative Eurocontrol-based CHI [4].

In order to quantify human performance, tasks and metrics were identified for use in CREM testing with controller subjects. The determination of appropriate metrics for different tasks (in context) will be refined as more data are gathered using the scientific method of discovery. Objective measures such as human response times for critical actions, frequency of verbal communications for co-ordination, memory recall for electronic flight strips and mental map recovery for situational awareness will be used to validate and correlate test data with subjective measures such as thinking aloud experiments and self assessment questionnaires. Both quantitative and qualitative data are needed to validate the proposed radical change to the existing CHI.

CREM Test Environment

CREM testing takes place in the Air Traffic Management Laboratory (ATM) at MIT Lincoln Laboratory. High-fidelity simulations are created based on live data to support controller-in-the-loop testing of the ODID-like CHI, validate CHI requirements and determine applicable standards for the design of an integrated CHI. Figure 6 is a photograph of the CREM with two DSR 20 inch square 2k x 2k color monitors accompanied by two pseudo pilot SUN ultra sparc workstations.

Figure 6. CREM in ATM Lab at MIT Lincoln Laboratory

CREM tests

CREM tests to date have been conducted with two pairs of Radar controller subjects using both the monochrome and the color-coded CHIs for two one hour test scenarios in a realistic simulation of Ft. Worth Center "live" traffic. The subjects were all experienced air traffic controllers supported by pseudo pilots "flying" multiple aircraft per the clearances issued by voice. Two important new CHI features, altitude changes and handoff indications, were studied and response time data were gathered automatically during the tests. The different conditions were counter balanced so each controller experienced each CHI after having enough practice to flatten the learning curve on the new CHI.

Results revealed that the new menu entry was (on average) two times faster than the existing keyboard entry for altitude changes when the cursor was defaulted or "anchored" on the next most likely entry in the menu. If the cursor default was not on the next entry, than the keyboard was somewhat faster. In noticing and accepting handoffs by clicking on the indicated targets, the yellow color was responded to faster than monochrome flashing indicator. In the color-coded new CHI condition, the entire tag was yellow upon entering the handoff area on the large screen and changed to white once the handoff was accepted. White was used to indicate owned aircraft for the sector while black was used to indicate aircraft that were being handed off to the next sector and grey was used to indicate aircraft that were not owned by the sector (referred to as "unconcerned" in the EATCHIP CHI). In the monochrome condition only white was used for all aircraft on a grey background, as in the EATCHIP CHI. Flashing of the sector number field in the data block was used to indicate handoffs rather than the yellow or black colors used in the new CHI. Figure 7 shows an inset of the radar screen for the old existing monochrome PVD (green on black) versus the new Eurocontrol-based CHI (multiple colors on two hues of grey). Since the concentration of this report is on lessons learned in designing a new CHI, detailed results are reported separately [5].

Lessons learned during the testing included evidence that the menu method is promising as a fast, easy entry for controllers changing an altitude, given that the computer automation is programmed to default the menu cursor on the next entry. In follow-up discussions with colleagues from the Eurocontrol Experimental Centre [6], it was learned that they had experienced the same (although the response times were not recorded). Color application is a complex issue, however lessons learned regarding its use were that given a neutral grey background, achieving enough contrast becomes difficult and a contrast ratio of 1:8 is recommended for legibility. Regarding the selected data block behavior, it was learned that cursor dwell time over a minimal display standard data block in order to expand it into a selected data block needs to be quite precise. The CREM was programmed to use a dwell time to display/clear of .25 seconds to preclude display of selected data blocks when not desired yet bring up a selected data with sufficient speed. A related lesson was learned in refining the buffer zone or active area surrounding the data block and menu so the clearing of a given object on the display would seem natural once the cursor was moved out of the active area.

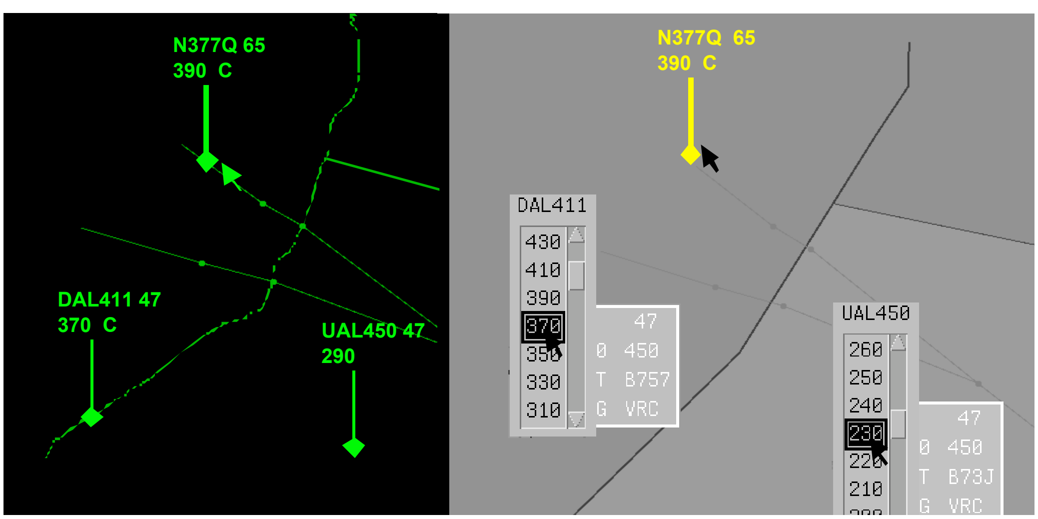

Figure 7. Old monochrome PVD versus New color CHI

Color Experiments

Separate, stand-alone experiments [7] were conducted on the application of display colors with various red green blue (RGB) values visually examined for legibility. Further study is needed to obtain luminance measurements with a photometer on the actual display to be used. Initial lessons learned regarding mixing different foregrounds and backgrounds indicated the following legible color combinations:

- Dimmed blue between (180,0,0) and (0,0,200) on grey (130,130,130) and higher.
- Dimmed red between (200,0,0) and (225,0,0) on grey (160,160,160) and higher.
- Pure green (0,255,0) on grey (130, 130, 130) and lower.
- Black (0,0,0) on grey (130,130,130) and higher.
- White (255,255,255) on grey (130,130,130) and lower.
- Pure bright yellow (255,255,0) on grey (150,150,150) and lower.
- Dimmed yellow (220,220,0) on darker grey shades (145) and darker.
- Dark brown like blue and black on grey (130,130,130) and higher.
- Cyan (0,255,255) on grey (150,150,150) and lower.

Note: Magenta and orange not legible on lighter greys (140 and higher) and barely legible on darker greys.

Specification Process

During the development of an alternative CHI, an initial specification of CHI requirements was drafted [8]. The intent of the alternative CHI requirements is to use the best of the Eurocontrol-based CHI ideas found in such systems as ODID, Denmark Sweden Interface (DSI), and EATCHIP while being mindful of FAA's DSR capabilities and limitations through contact with the US vendor. In the development process, typical human factors issues of an interactive CHI must be resolved. Requirements are documented in order to provide a consistent look and feel for the alternate CHI proposed to be used as an improvement to Free Flight Phase 1. During this process, an important lesson was learned. Controllers need to understand a new CHI by actually experiencing it. As one controller stated, they need to "see it, touch it, feel it." While detailed specifications of the CHI, such as shown in Figure 8, are needed to precisely define requirements for software development, the controllers (or end users) need a more effective means of communication.

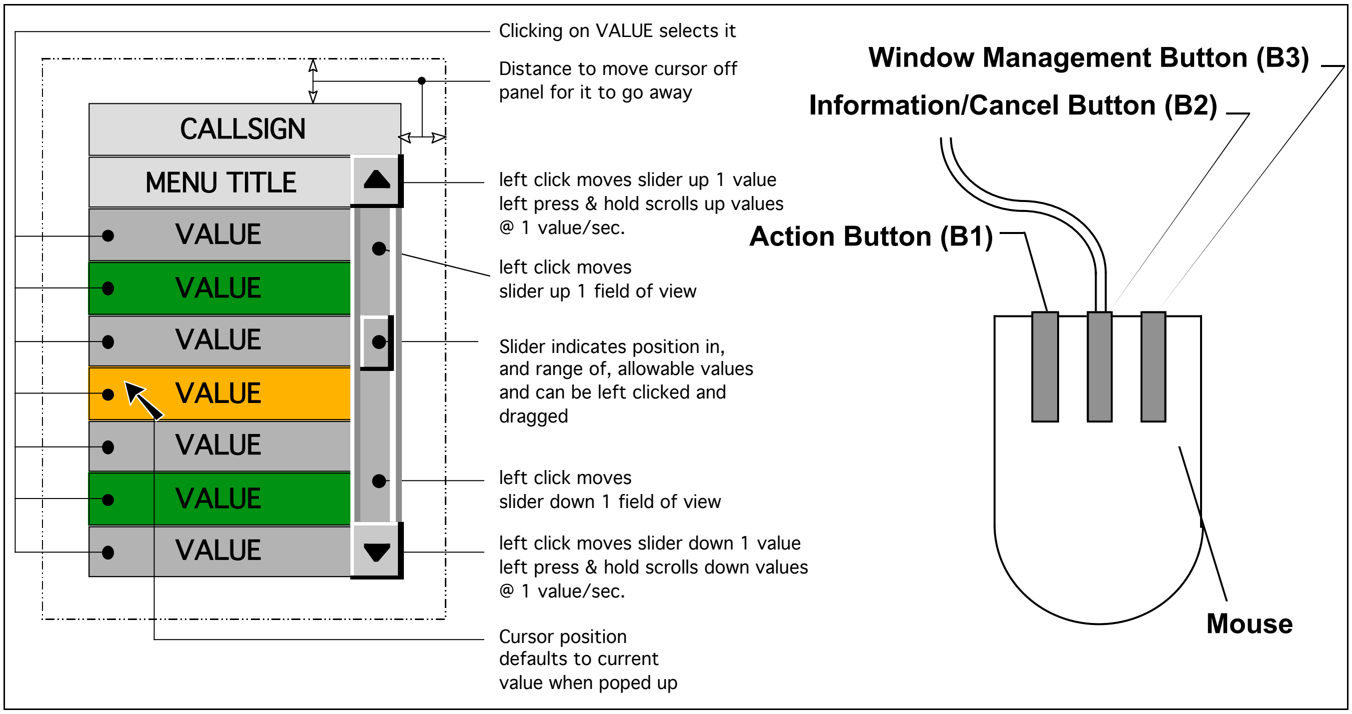

Figure 8. Example detailed specifications of the CHI

CHI Integration Issue

New decision support tools will be used by en route controllers in the near term future with the advent of FFP1. Initially the tools will be presented separately and any integrated use will be by procedure. However, eventually the tools - which currently have disparate CHIs - will by systematically integrated. Their individual CHIs have some key similarities and differences, such as transparency of windows, use of color, and style of presentation. Redundancy and style of presented information must be considered as an important human factors issue to be resolved for an integrated CHI. One example highlighting this issue is shown in figures 9-11 with screen snapshots of various lists, two from FFP1 and one from Eurocontrol CHI.

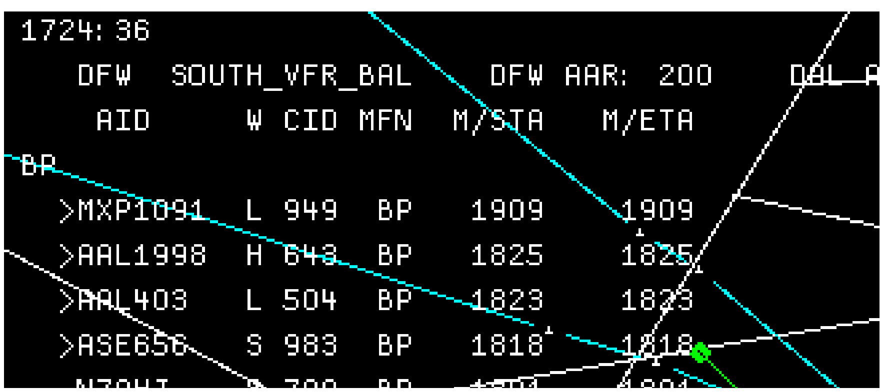

Figure 9. Sequence List from Traffic Management Advisor

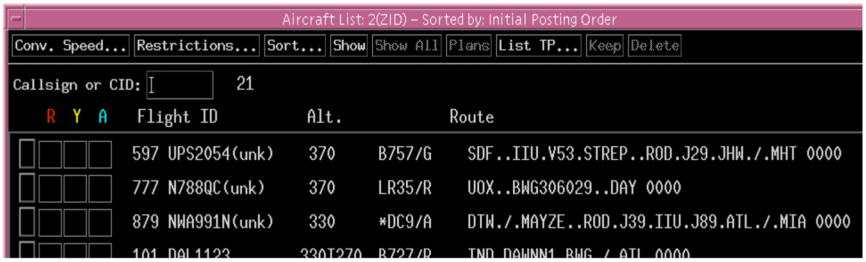

Figure 10. Aircraft List from User Request Evaluation Tool

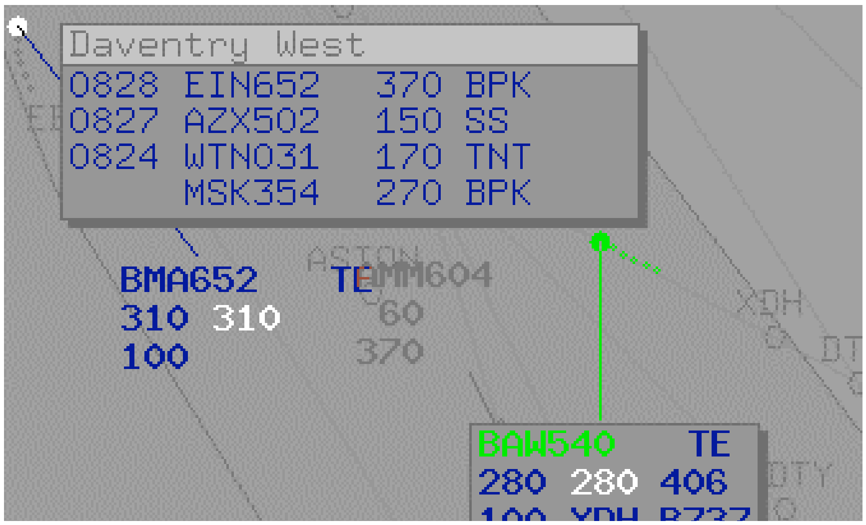

Figure 11. Sector Inbound List from EATCHIP

Summary

Some key initial lessons about process have been learned during the early development of an alternate Eurocontrol-based CHI [9 and 10] for en route air traffic control using DSR in the US. Beginning with a positive response to the new CHI presented as part of a proposed operational concept to air traffic requirements managers and controllers, MIT Lincoln Laboratory built a CHI requirements engineering model (CREM) to exercise the CHI prototype in high fidelity simulations. Applicable metrics were defined for the ATC domain in order to measure controller performance using the Eurocontrol based CHI. Initial test results were promising and it became clear that prototyping with the CREM is an effective means to communicate alternate CHI design ideas and obtain objective measures to back up subjective opinions.

A specification of the initial alternate CHI requirements has been drafted to specify details, however such requirements should be validated when possible through prototyping and experimentation so objective data will support design decisions. Ultimately, the lesson learned in terms of the CHI development process is that prototyping and user involvement is essential for successfully determining operational suitability at the earliest feasible stage – especially when the CHI change is radical.

Another lesson learned in examining the Eurocontrol-based CHI advances and the rational behind them is that controllers need to be prepared for a culture change. It is fortunate that the new generation is computer literate because CHI changes employing modern graphical technology (such as in the Eurocontrol-based CHI) will be needed to manage demand and increase system capacity. The alternative ODID-like CHI design, test, and technology transfer work is ongoing to support the FAA's ultimate goal of deploying an operationally suitable interface for air traffic service providers in the near-term future.

Finally, while change can be accompanied by anxiety, the lesson is that anxiety can be alleviated by communication. The goal of communication is to disseminate relevant information effectively, that is, in a manner understood by the recipients. Once communication has been achieved, then concensus (where appropriate) has a chance of being realized. For air traffic control, which is a highly visual and hands-on activity, allowing users to experience a CHI prototype as it evolves appears to be a most effective means of communication.

Therefore, it is recommended that a web site be developed to demonstrate alternative CHI designs with interactive scenarios highlighting innovative CHI design ideas. The web site should be monitored and managed to gain feedback from both the research and user community. Current thoughts, validated designs and future directions in the evolution of an alternative CHI should appear on the web site to feed a living document that could eventually become an animated specification with buy in from the users. Eurocontrol currently provides an EATCHIP HMI [11] site from their EUROCONTROL HQ Division DED-2 HMI Sub-section in Belgium. This model web site has added a discussion group currently being used to facilitate user feedback on new design ideas. Ultimately, the human factors research community, working together with the controller community, should strive toward establishing an acceptable CHI standard or at least guidelines, similar but not necessarily the same as software graphical user interface standards such as MOTIF [12]. The CHI standard would form a baseline for system upgrades such as the decision support tools to be deployed in the near future for en route ATC.

Acknowledgments

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