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# Human-in-the-Loop Simulation Evaluating the Collocation of the User Request Evaluation Tool, Traffic Management Advisor, and Controller-Pilot Data Link Communications: Experiment I – Tool Combinations

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16. Abstract

The Federal Aviation Administration (FAA) Free Flight Program successfully deployed the User Request Evaluation Tool (URET), Traffic Management Advisor (TMA), and Controller-Pilot Data Link Communications (CPDLC) to a limited number of Air Route Traffic Control Centers (ARTCCs). As deployment expands nationwide, several facilities may eventually receive all three tools. Before this occurs, it is important to identify any potential human factors issues that may arise due to the collocation of these tools at the controller's workstation. In this report, we present the first of three high fidelity human-in-the-loop simulation experiments we conducted to evaluate the impact of URET, TMA, and CPDLC collocation on controller workload, situational awareness, and teamwork. We examined collocation issues with a "stovepipe" independent configuration where none of the tools were integrated or directly communicated with each other. In this first experiment, twelve Air Traffic Control Specialists (ATCSs) participated as R-side/D-side controller teams operating a high altitude generic sector using all combinations of the three tools. The most important collocation issue identified was that controllers had difficulty accessing important information on the D-side display when URET and CPDLC were both operational (i.e., display clutter). Although neither tool alone caused display clutter, both tools in combination made it difficult for D-side controllers to find the information they needed quickly. This was especially true for accessing CPDLC windows, which became covered when controllers used URET. Another collocation issue was that D-side controllers had to access TMA delay time information from the R-side display. Controllers thought it was important to have TMA information available on the D-side display where it could be easily accessed by D-side controllers. However, controllers were concerned that simply showing the TMA List on the D-side might add to the D-side display clutter. Good human factors design principles prescribe that users must have immediate access to important information and that critical information should never be covered. A "stovepipe" independent deployment of these tools will result in impaired access to timely information. The results of this study indicated that better efforts should be made towards integrating the information from URET, TMA, and CPDLC on the D-side monitor prior to deployment.

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# Executive Summary

The Federal Aviation Administration (FAA) established the Free Flight Program in collaboration with the aviation community to increase capacity (airport and airspace) and improve efficiency (flight times and fuel consumption) while maintaining the current high level of safety. An important goal of the Free Flight Program was the delivery of new air traffic control (ATC) technologies focused on early benefits to users of the National Airspace System (NAS). These capabilities included the User Request Evaluation Tool (URET), Traffic Management Advisor (TMA), and Controller-Pilot Data Link Communications (CPDLC) as en route controller tools. Under the Free Flight Program, the FAA deployed these tools independently to a limited number of Air Route Traffic Control Centers (ARTCCs) nationwide. As deployment expands to other facilities, all three tools may be collocated at the sector workstation.

Different designers developed URET, TMA, and CPDLC with the assumption that each system would operate independently. As tool deployment expands nationwide, several facilities may eventually receive all three tools. Before this occurs, it is important to identify any potential human factors issues that may arise due to the collocation of these tools at the controller's workstation. For example, will controllers be able to access the information they need quickly without confusing data from different systems? How will controller communications between team members be affected? How will the collocation of these tools change the roles and responsibilities of team members? What new training or procedures may be required? The FAA Free Flight Program Office (AOZ) and the Human Factors Research and Engineering Division (ATO-P) sponsored this research to address these important questions.

In this report, we present the first of three human-in-the-loop simulation experiments we conducted to evaluate the impact of URET, TMA, and CPDLC collocation on controller workload, situational awareness, and teamwork. The first experiment examined R-side/D-side controller teams working a high altitude sector using different combinations of the three tools at a single sector. The second experiment examined controller teams interacting with each other while working a high and a low altitude sector and using all of the tools. The third experiment examined controllers working a high altitude sector alone without a D-side and using all of the tools. We will present the second and third experiments in a subsequent report.

Twelve Air Traffic Control Specialists (ATCSs) from Level 11 and Level 12 ARTCCs nationwide participated in this study. We recruited six participants from ARTCCs where URET is operational and six participants from ARTCCs where TMA is operational. All six ATCSs from the URET facilities were URET current and proficient. However, only five ATCSs from the TMA facilities were TMA current and proficient. The participant who was not TMA qualified, received TMA training on our ATC simulator. We trained all twelve participants in CPDLC after arriving at the FAA, William J. Hughes Technical Center (WJHTC). Also, all participants received some cross-training in URET and TMA. Each controller team consisted of one TMA-qualified ATCS operating the R-side (Radar) and one URET-qualified ATCS operating the D-side (Data) position.

We conducted the experiment in the FAA, WJHTC Research, Development, and Human Factors Laboratory (RDHFL) using our high fidelity ATC simulator, the Distributed Environment for Simulation, Rapid Engineering, and Experimentation (DESIREE). DESIREE emulated en route

Display System Replacement (DSR) functions and was configured with URET and TMA prototypes, as well as CPDLC Build 1A functionality. We deployed TMA and CPDLC on the R-side Sony 2K monitor and URET and CPDLC on the D-side 21" flat-panel monitor. The CPDLC services were: Transfer of Communications (TOC), Altimeter Setting (AS), Initial Contact (IC), and Menu Text (MT) Messages.

The study consisted of three 2-week sessions with a different group of four ATCSs participating in each session. In the first week, controllers completed 18 hours of practice scenarios to become familiar with the generic high altitude sector selected for this simulation and the three tools. In the second week, controllers completed eight test scenarios under experimental conditions with different combinations of URET, TMA, and CPDLC. In a baseline condition, participants controlled traffic without any tools. In other conditions, participants completed scenarios using each tool separately, as well as two and three tools together. We counterbalanced the presentation order of the eight tool combinations to experimentally control for practice effects.

The most important collocation issue identified in this experiment was that controllers had difficulty accessing important information on the D-side display when URET and CPDLC were both operational (i.e., display clutter). Controller ratings indicated that CPDLC caused a great deal of display clutter on the D-side monitor. Neither URET alone nor CPDLC alone caused display clutter. However, both tools in combination made it difficult for D-side controllers to find the information they needed quickly. This was especially true for accessing CPDLC windows, which became covered when controllers used URET.

It is important to note the controllers identified this D-side display clutter issue using the D-side CPDLC CHI we developed in the RDHFL for use in this simulation study. We designed the D-side CHI to be consistent with a "stovepipe" independent deployment of the tools with simple features to help controllers manage the multiple windows associated with each tool. This specific D-side CHI was not intended to be the interface that will be deployed to ARTCCs in the future.

Another collocation issue identified in this experiment was that D-side controllers had to access TMA delay time information from the R-side display. Controllers thought it was important to have TMA information available on the D-side display where it could be easily accessed by D-side controllers. However, controllers were concerned that simply showing the TMA List on the D-side might add to the D-side display clutter.

Controller workload ratings indicated that D-side workload tended to increase when two and three tools were operational. However, D-side workload ratings were only moderate and never reached a high level for the moderate traffic scenarios we used in the simulation. We also examined the number of ground-to-air voice transmissions and airspeed, heading, and altitude changes as additional indicators of controller workload. None of these measures increased greatly with multiple tool use.

In general, controllers rated their situational awareness as very high during the simulation. However, there was a situational awareness issue with the CPDLC TOC service. R-side controllers sent most of the CPDLC TOCs to aircraft. Although D-side controllers did not use the TOC service very often, controllers still expressed concern about not knowing what their team member was doing with CPDLC. Unlike voice communications, there were no audible cues with CPDLC to help controllers maintain situational awareness of their team member's actions. Controllers had to visually monitor the CPDLC Message Out window to know when their team member sent a TOC message. If the CPDLC display was covered by URET, the D-side controller could easily miss a sent message.

Good human factors design principles prescribe that users must have immediate access to important information and that critical information should never be covered. A "stovepipe" independent deployment of these tools will result in impaired access to timely information. The results of this study indicated that better human factors efforts should be made towards integrating the information from URET, TMA, and CPDLC. Even if these systems cannot be entirely integrated, we should explore integrating the displays on the D-side monitor prior to deployment.

## 1. Introduction

In 1998, the Federal Aviation Administration (FAA) established the Free Flight Program in collaboration with the aviation community to increase capacity (airport and airspace) and improve efficiency (flight times and fuel consumption) while maintaining the current high level of safety. An important goal of the Free Flight Program was the delivery of new air traffic control (ATC) technologies focused on early benefits to users of the National Airspace System (NAS). These capabilities included the User Request Evaluation Tool (URET), Traffic Management Advisor (TMA), and Controller-Pilot Data Link Communications (CPDLC) as en route controller tools. Under the Free Flight Program, the FAA deployed these tools independently to a limited number of Air Route Traffic Control Centers (ARTCCs) nationwide. As deployment expands to other facilities, all three tools may be collocated at the sector workstation.

Designers developed the three systems independently; therefore, we need to investigate how Air Traffic Control Specialists (ATCSs) will interact with the three tools before they are deployed together at the same sector. When evaluating tools that will introduce changes or add to the number of systems used in ATC, it is important to identify any potential problems that might arise from the introduction of these new tools. Identifying problems and correcting them before they can negatively impact performance in the field is critical in ATC where safety is potentially at stake. Therefore, the FAA Free Flight Program Office (AOZ) and the Human Factors Research and Engineering Division (ATO-P) sponsored this study to examine the impact of collocating URET, TMA, and CPDLC at the controller's workstation.

In this report, we present the first of three separate experiments we conducted to assess the human factors issues of collocating URET, TMA, and CPDLC. The first experiment examined R-side/D-side controller teams working a high altitude sector using different combinations of the three tools at a single sector. The second experiment examined controller teams interacting with each other while working a high and a low altitude sector and using all of the tools. The third experiment examined controllers working a high altitude sector alone without a D-side and using all of the tools. We will present the second and third experiments in a subsequent report.

### 1.1 Background

#### 1.1.1 Previous Research

Several studies have examined issues related to the collocation of URET, TMA, and CPDLC. Desenti, Gross, and Toma (2000) examined the use of URET and TMA. The authors questioned whether there was an emerging concept of use for URET and TMA in which the trial planning capability of URET may be compatible to meet the metering times of TMA. A potential human factors issue arising from this study was that URET and TMA used different algorithms to compute an aircraft's future location.

The NAS Advanced Concepts Branch at the FAA, William J. Hughes Technical Center (WJHTC) performed the second study. These researchers conducted a real-time human-in-the-loop (HITL) simulation that examined the use of URET Core Capability Limited Deployment (CCLD) and TMA. They determined that the URET list sequences were different from the aircraft sequences on TMA. However, they concluded that, because URET and TMA were independent tools, there should be little or no negative impact on safety.

In a third study, Kerns (2001) of the MITRE Center for Advanced Aviation System Development examined the human factors issues related to collocating URET and CPDLC. She concluded that the Data (D)-side workload would increase, and the design of the Computer Human Interface (CHI) on the D-side was critical to the successful deployment of URET and CPDLC. Kerns also noted there would be changes in the roles and responsibilities of the Radar (R)-side and D-side positions.

Della Rocco, Panjwani, Friedman-Berg, Kopardekar, and Hah (in press) performed a fourth study. These researchers conducted a "cognitive walkthrough" that explored the collocation of URET, TMA, and CPDLC. The cognitive walkthrough is a technique that human factors researchers use to evaluate the design of a user interface, with special attention to how well the interface supports first-time use without formal training. Della Rocco et al. raised questions about how the three tools update the NAS. They also identified a number of CHI inconsistencies across the three tools. They concurred with Kerns (2001) that when all three tools were deployed together, the roles and responsibilities of the R-side and D-side positions needed clarification. Further, applying human factors principles to these issues will help ATCSs use the tools as intended and attain the expected benefits.

As stated previously, researchers have conducted subjective evaluations of these tools (Desenti, Gross, & Toma, 2000; Kerns, 2001). Whereas Desenti, Gross, and Toma (2000) investigated the collocation of URET and TMA, and Kerns (2001) examined the collocation of URET and CPDLC; neither study involved a real-time HITL simulation. In the study performed at the NAS Advanced Concepts Branch (2001), researchers conducted a real-time HITL simulation that examined the collocation of URET and TMA. That study, however, gathered no objective performance measures. Della Rocco et al. (in press) explored the collocation of URET, TMA, and CPDLC by performing a cognitive walkthrough using Subject Matter Experts (SMEs) to identify potential human factors issues related to the deployment of the three tools at the same sector. To date, there are no real-time HITL simulation studies that have objectively examined ATCS performance while employing all three tools.

Researchers have made several recommendations related to human factors issues involving real-time HITL simulations. First, Della Rocco et al. (in press) recommended that the inconsistencies in the CHIs across systems should be examined for their impact on actual ATC performance. Second, a real-time HITL simulation should examine the procedures defining the roles and responsibilities for the R-side and D-side positions and where to implement those procedures. More specifically, they further recommended the need to examine the effect of the increased information from all three tools (i.e., URET, TMA, and CPDLC), the effect of the increased communication requirements, the effect of the different tools updating NAS, any issues related to clutter on both the R-side and D-side, and any issues unique to a single R-side operation. Thus, an HITL simulation was the logical next step to evaluate the collocation of these three tools at the en route sector workstation.

### 1.1.2 Human Factors Issues

In this study, we examined the primary issues of whether there will be any change in controller performance, workload, or situational awareness (SA) due to the collocation of URET, TMA, and CPDLC. Best human factors practices recommend that information be provided to ATCS in a timely manner that is consistent with other information and easily understood by the ATCS. Otherwise, there may be a detrimental impact on performance, workload, and SA. In addition, when URET and CPDLC are collocated on the D-side, there may be an increase in communication between the R-side and D-side, which again may have a significant impact on controller performance, workload, and SA (Cardosi & Murphy, 1995). Furthermore, a "stovepipe" independent deployment of the three tools will result in information being presented over a more diverse area requiring the controller to not only search for the appropriate data, but also to integrate it.

### 1.1.3 Real-Time Human-in-the-Loop Simulation

One of the best ways to gain valuable insight into the impact of new automation and controller tools is to conduct real-time HITL simulations (Manning, 2000), where ATCSs interact with realistic models of the tools and perform as they would in an actual Air Route Traffic Control Center (ARTCC). As Manning points out, real-time HITL simulations "allow controllers to direct the activities of a sample of simulated air traffic, performing characteristic functions such as ordering changes in aircraft speed or flight path, all within a relatively standardized work sample." In this study, we conducted a real-time HITL simulation to explore how the collocation of URET, TMA, and CPDLC will affect ATCS performance. HITL simulations surface issues that would not otherwise be apparent until after deployment.

### 1.2 Assumptions

The assumptions for the current study were the same as those adopted for the cognitive walkthrough study conducted by Della Rocco et al. (in press). Specifically,

a. The system will represent today's Display System Replacement (DSR) environment with the BCC21 CHI designed by the Air Traffic Design Evolution Team (ATDET). The D-side position will have a 21" flat panel monitor that is used to display URET and the D-side Computer Readout Display (CRD). This same monitor will display CPDLC information in our simulation.

b. The system will be implemented with URET, TMA, and CPDLC being independent and not having direct communication with each other, but each tool will communicate to and from the simulated host computer.

c. Controllers will procedurally use CPDLC only for non-time-critical instructions to pilots, and the tool will be available at both the R-side and D-side positions.

d. To implement CPDLC at both positions for the present study, the D-side position will have CPDLC windows on the D-side monitor similar to the ATDET CPDLC Build IA windows on the R-side. These will be the CPDLC Message Out, Menu Text, and History windows with the same interactive capability in these windows allowed on the R-side.

e. In addition, the D-side controller will be able to use text-based commands in the D-side CRD as well as "hot keys" on the D-side keyboard for CPDLC functions.

f. The D-side position will not have interactive aircraft data blocks for CPDLC functions.

g. The URET Aircraft List will replace paper flight progress strips in CCLD (FAA, 2002) as in the deployments at Memphis and Indianapolis ARTCCs.

### 1.3 Purpose

We intended the present study to be the first in a series of studies that will examine the collocation of URET, TMA, and CPDLC with the following general purposes:

a. assess the human factors implications of collocating these three tools at the same sector,

b. understand the cumulative effects from a research perspective on workload, SA, and teamwork,

c. identify areas in which mitigation strategies are needed before the tools are deployed, and

d. assess the efficiency and capacity benefits of collocating these three tools at the same sector.

We used the work performed by Della Rocco et al. (in press) and others (Desenti et al., 2000; Kerns, 2001) to design and conduct a real-time HITL simulation that explored whether the collocation of URET, TMA, and CPDLC tools had any impact on ATCS performance, workload, and SA. In the first experiment, we examined all possible combinations of these three tools with both R-side and D-side controller teams. In a second experiment, we examined a high altitude and a low altitude sector configuration to determine if ATCS performance differs as a function of sector characteristics. In a third experiment, we investigated ATCS performance when working the R-side position unassisted. The results of the second and third experiments will follow in a subsequent report. In this report, we present the results from the first experiment.

### 1.4 Specific Objectives

The specific objectives of the present study are

1. to assess whether controllers have access to information when needed and whether they interpret available information correctly,
2. to assess R-side/D-side roles and responsibilities,
3. to assess R-side/D-side teamwork and communications,
4. to assess R-side/D-side workload and workload distribution,
5. to identify information interactions between the tools that require resolution, and
6. to surface any other important human factors issues not previously anticipated.

## 2. Method

### 2.1 Participants

Ten male and two female ATCSs from Level 11 and Level 12 ARTCCs nationwide participated in this study. We recruited six participants from ARTCCs where URET is operational and six participants from ARTCCs where TMA is operational. All six ATCSs from the URET facilities were URET current and proficient. However, only five ATCSs from the TMA facilities were TMA current and proficient. The participant who was not TMA qualified, received TMA training on our ATC simulator. We trained all twelve participants in CPDLC after arriving at the WJHTC. Also, all participants received some cross-training in URET and TMA. Each controller team consisted of one TMA-qualified ATCS operating the R-side and one URET-qualified ATCS operating the D-side position.

All participants were nonsupervisory, certified professional controllers who were qualified at their facility and held a current medical certificate. The medical certification ensured that all participants were in good health and had normal or corrected-to-normal vision and hearing. The controllers completed an Informed Consent Form (Appendix A) prior to participating in the study. The consent form described the study and stated that participation was voluntary and that controllers may withdraw from the study at any time for any reason.

Each controller completed a Background Questionnaire (Appendix B) to describe the general demographic characteristics of participants in the study. The controllers ranged in age from 28 to 47 years old with a mean of 40.52 years and ranged in FAA experience from 5 to 21 years of active service with a mean of 15.10 years. All participants actively controlled traffic for the past 12 months.

### 2.2 Test Facility and Equipment

We conducted the simulation in the FAA, WJHTC Research, Development, and Human Factors Laboratory (RDHFL). The simulation configuration consisted of the Distributed Environment for Simulation, Rapid Engineering, and Experimentation (DESIREE) and the Target Generator Facility (TGF). DESIREE emulated en route DSR functions and received input from the TGF to display radar targets. The DESIREE simulation support team connected the URET CCLD and TMA prototypes and emulated CPDLC functionality. The TGF maneuvers aircraft based upon simulation pilot commands and scripted flight plan data. Table 1 identifies the specific tools, the version, and the functions that DESIREE provided.

Table 1. Controller Tools

| Tool | Version | Primary Capabilities |
|---|---|---|
| URET | MITRE URET prototype, version 4.1 | • Automated conflict detection<br>• Trial planning<br>• Trajectory modeling<br>• Routing changes<br>• Electronic flight data management |
| TMA | NASA Center TRACON Automation System (CTAS), version 6.0.1 | • Estimated times of arrival to outer meter arc, meter fix, final approach fix, and runway threshold<br>• Aircraft sequence and scheduled times of arrival<br>• Time each aircraft must gain/lose to meet maximally efficient arrival rates |
| CPDLC | DESIREE emulation, (formerly Build IA) | • Transfer of communications (TOC)<br>• Altimeter setting (AS)<br>• Initial contact (IC)<br>• Menu text messages (MT) |

Each R-side workstation consisted of a high-resolution Sony 2K monitor, DSR R-side keyboard, and 3-button trackball. TMA and CPDLC were on the R-side Sony 2K monitor. Each D-side workstation consisted of a 21” flat-panel monitor, DSR D-side keyboard, and mouse. We deployed URET and the CPDLC windows on the D-side 21” flat-panel monitor. The voice communications system consisted of individual relay switchboxes, controller headsets with microphones, and push-to-talk handsets or foot pedals. Flight strip marking was optional in our simulation; however, we informed controllers that strips could be posted to their position when URET was not operational. Only one of the controller teams requested and marked flight progress strips.

We set up the controller workstations in one experiment room. Engineering research psychologists and a software engineer operated the data collection equipment and monitored the simulation from an adjacent room. An SME observed over-the-shoulder of each controller team and provided ratings and comments on controller interaction with the tools. Three experienced simulation pilots supported each controller team from pilot workstations in a remote room of the same building. The simulation pilots communicated with controllers using proper ATC phraseology and procedures and maneuvered aircraft using simple keyboard commands.

2.2.1 Airspace

We selected a generic high altitude en route sector as the airspace for this simulation (Figure 1). Appendix C describes the merits of using generic airspace in real-time HITL simulations. We decided upon a high altitude sector after visiting Indianapolis and Los Angeles ARTCCs and consulting with the user groups for each of the tools. SMEs with specific knowledge of URET and TMA operation in the field advised the research team to use a high altitude sector. The rationale was that both tools are probably more effective in high altitude sectors where URET conflict detection is less complex and TMA delays are longer. Also, we discussed the generic high altitude sector with the CPDLC Program Office and National Air Traffic Controller Association (NATCA) representatives of the CPDLC user team who were satisfied that the sector would be adequate for CPDLC usage as well.

Researchers and SMEs with the NAS Human Factors Group (ATO-P) designed this generic high altitude sector to be a realistic environment for controlling traffic and easy for ATCSs to learn (Guttman & Stein, 1997). The airspace consisted of easily remembered "fix" names and simplified operating procedures to facilitate learning. The generic sector was roughly rectangular in shape and extended for approximately 120 nm from north to south, approximately 100 nm from east to west, and from Flight Level (FL) 240 and above in altitude. Arrival routes flowed in a southbound direction and departure routes flowed in a northbound direction. The sector contained several intersections that contributed to complexity and crossing restrictions for realism. The high altitude sector was adjacent to a generic low altitude sector. The low altitude sector served as transition airspace controlling traffic flow into the terminal region that had one major airport and three satellite airports. In this experiment, the sectors adjacent to the high altitude sector were automated by "ghost" controller functionality.

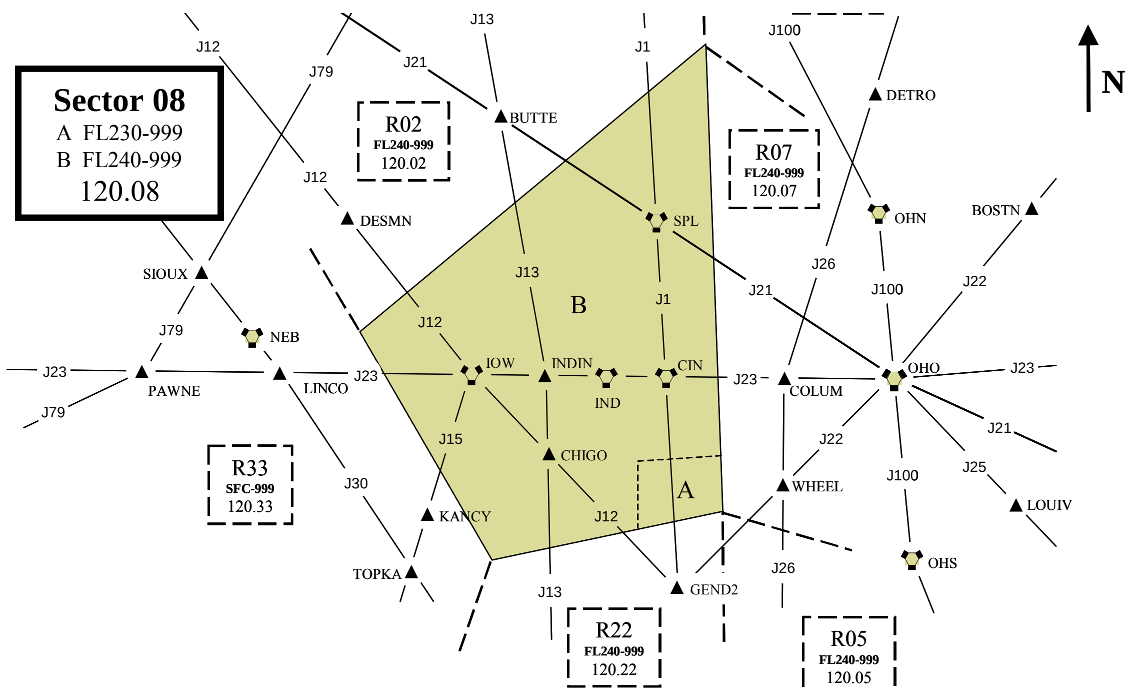


Figure 1. Generic high altitude airspace.

### 2.2.2 Traffic Scenarios

The researchers selected traffic scenarios from previous studies in the RDHFL and modified them to meet the objectives of the present study. We developed eight similar test scenarios and 18 practice scenarios. We designed the test and practice scenarios with similar traffic patterns and levels. All test scenarios were 45 minutes in duration. The practice scenarios were 45 to 60 minutes in duration.

SMEs designed the traffic scenarios with moderate traffic levels. The operational definition of moderate traffic for this study was traffic that was busy enough to require metering, but not so busy as to overwhelm controllers who were not experienced with all of the tools. We prepared one basic test scenario with 81 total aircraft (43 arrivals, 6 departures, and 32 overflights). We designed the other test scenarios based on the basic scenario with the same number of arrivals, departures, and overflights. However, we changed the aircraft entry times and assigned different callsigns to the aircraft in each of the other scenarios. This ensured that all test scenarios were similar in traffic, but not recognizable as the same scenario.

When CPDLC was in use, 40% of the aircraft in the scenarios were equipped. The default setting for CPDLC was manual Transfer of Communications (TOC) mode that was operational with auto handoff mode in DSR. In manual TOC mode, CPDLC will generate a held TOC message that must be released by either the R-side or D-side controller for the system to uplink a new frequency to aircraft. We allowed the participants to decide for themselves which team member would release aircraft with held TOCs. In the CPDLC system, controllers can always override the manual TOC mode for an individual aircraft and allow the system to automatically uplink a new frequency when the aircraft is handed off.

## 2.3 Experiments

### 2.3.1 Independent Variables

The experiment represented a 2-factor design with R-side and D-side controller positions as the first factor and eight different tool combinations as the second factor (Table 2). The ATCSs participated in eight scenarios, with each scenario representing a different tool combination. We counterbalanced the presentation of the tool combinations to experimentally control for practice effects. Although there were two teams of ATCSs participating simultaneously, each team independently controlled different traffic scenarios in the high altitude sector.

Table 2. Experimental Design

| **Positions** | **R-side and D-side Controller Teams** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Tools** | None | U | T | C | UT | UC | TC | UTC |
| None-No Tools (Baseline) U-URET T-TMA C-CPDLC | | | | | | | | |

2.3.2 Dependent Variables

In our real-time HITL simulations, we collect a large set of standard system effectiveness measures for ATC simulation research that include safety, capacity, efficiency, and communications indicators (Buckley, DeBaryshe, Hitchner, & Kohn, 1983; Stein & Buckley, 1992). We examined all the objective measures we collected to understand what controllers did in our simulation. For this report, we selected a few measures that were directly influenced by these tools. Table 3 presents these objectives measures.

Table 3. Objective Measures

| |
|---|
| Number of CPDLC TOC messages sent |
| Number of controller ground-to-air voice communications |
| Number of controller assigned airspeed, heading, and altitude changes |
| Number of controller handoffs accepted and initiated |
| Number of controller flight plan readouts |
| Flight distance and flight time (per aircraft) within the sector |
| Aircraft loss-of-separation within the sector |

In our real-time HITL simulations, we also collect a large set of subjective measures that include controller workload and SA measures, SME ratings and observations, and participant questionnaires. We examined all the subjective measures we collected to identify any potential human factors issues in this study. For this report, we selected a few measures that were directly influenced by these tools. Table 4 presents these subjective measures.

Table 4. Subjective Measures

| |
|---|
| Controller ratings of display clutter |
| Controller workload ratings obtained from ATWIT |
| Controller workload ratings obtained from NASA-TLX: Mental Demand |
| Controller situational awareness ratings |
| Observer ratings of controller overall prioritization |
| Controller simulation realism ratings |

The ATCSs provided workload ratings using two different techniques. The first technique was the ATWIT, a real-time uni-dimensional workload rating method. ATWIT provides an unobtrusive and reliable means for collecting self-report workload ratings as the ATCS manages air traffic (Stein, 1985, 1991). A personal computer and 10-button keypad collected and recorded participant responses. The participants indicated their current workload by pressing one of the keypad buttons labeled from 1 (low workload) to 10 (high workload). The system prompted participants for input every five minutes by emitting several beeps and lighting the buttons on the keypad. Participants had 20 seconds to respond by pressing one of the 10 buttons. If the ATCS did not respond within 20 seconds, ATWIT recorded a default symbol indicating there was no response.

The second technique we used to measure workload was the NASA-TLX (Hart & Staveland, 1987). The ATCSs completed this multi-dimensional workload rating method at the conclusion of each scenario. The six dimensions on which the NASA-TLX focuses are mental demand, physical demand, temporal demand, performance, effort, and frustration. We used a modified procedure that included all six workload subscales, but did not use the sorting technique that assigns subjective weights to the subscales.

An SME unobtrusively observed each controller team and made over-the-shoulder ratings of ATCS performance during the scenarios. The SMEs used an observation form specially designed for ATC performance evaluation research (Sollenberger, Stein, & Gromelski, 1997; Vardaman & Stein, 1998). The observation form consists of 27 different rating scales organized into 6 major ATC performance categories. The SMEs received extensive training in the use of these rating scales.

### 2.4 Training

The SMEs also acted as instructors and trained the participants to become proficient with the generic airspace and familiar with the URET, TMA, and CPDLC systems. Training on the airspace and tools consisted of an overview presentation and 18 hours of practice scenarios. Participants completed airspace and tool training over the course of four days.

### 2.5 Procedure

Table 5 shows the daily schedule for each 2-week session. Four controllers participated in each testing session. Monday of the first week and Thursday of the second week were scheduled for travel. On the first Tuesday, the researchers briefed the participants on the project goals, airspace operations, and support tools followed by three 60-minute practice scenarios and a question and answer period at the end of the day. Wednesday, Thursday, and Friday of the first week consisted of five 60-minute practice scenarios each day. The following week, Monday, Tuesday, and Wednesday consisted of four test scenarios and a group discussion at the end of each day. Participants worked from 8:00 AM to 4:30 PM with a 90-minute lunch period and a 30-minute break after each scenario. On the first day of the study, participants signed an Informed Consent Form (Appendix A) and completed a Background Questionnaire (Appendix B). The participants completed a Post-Scenario Questionnaire (Appendix D), and the SMEs completed Observer Rating Forms (Appendix E) after each test scenario. On the last day of the study, the participants completed an Exit Questionnaire (Appendix F).

Table 5. Daily Schedule

| Tues | | Wed, Thurs, Fri | | Mon, Tues, Wed | |
|---|---|---|---|---|---|
| **Time** | **Activity** | **Time** | **Activity** | **Time** | **Activity** |
| 8:00 - 10:00 | Project Briefing, Overview, and Initial Forms | 8:00 - 9:00 | Practice Scenario | 8:00 - 8:30 | Warm-up Scenario |
| | | 9:00 - 9:30 | Break | 8:30 - 9:00 | Break |
| | | 9:30 - 10:30 | Practice Scenario | 9:00 - 9:45 | Test Scenario |
| 10:00 - 10:30 | Break | 10:30 - 11:00 | Break | 9:45 - 10:15 | Break |
| 10:30 - 11:30 | Practice Scenario | 11:00 - 12:00 | Practice Scenario | 10:15 - 11:00 | Test Scenario |
| 11:30 - 1:00 | Lunch | 12:00 - 1:30 | Lunch | 11:00 - 11:30 | Break |
| 1:00 - 2:00 | Practice Scenario | 1:30 - 2:30 | Practice Scenario | 11:30 - 12:15 | Test Scenario |
| 2:00 - 2:30 | Break | 2:30 - 3:00 | Break | 12:15 - 1:45 | Lunch |
| 2:30 - 3:30 | Practice Scenario | 3:00 - 4:00 | Practice Scenario | 1:45 - 2:30 | Test Scenario |
| 3:30 - 4:00 | Break | 4:00 - 4:30 | Group Discussion | 2:30 - 3:00 | Break |
| 4:00 - 4:30 | Question & Answer | | | 3:00 - 4:30 | Group Discussion |

Table 6 shows the counterbalancing order for the experimental conditions. We presented eight scenarios for each R-side/D-side team of participants. The conditions were randomized differently for each group of participants. The scenarios were similar in traffic level, but we changed the aircraft entry times and assigned different callsigns to each aircraft in the scenarios. The participants completed four test scenarios each day after a preliminary warm-up scenario. Before each scenario, the researchers informed the participants which tool or tools would be operational.

Table 6. Experimental Condition Counterbalancing

| | Presentation Order of Experimental Conditions | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Controllers** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** |
| **S01, S02** | TC | U | UC | C | UT | UTC | T | None |
| **S03, S04** | UT | C | U | UTC | UC | None | TC | T |
| **S05, S06** | UC | TC | C | U | T | UT | None | UTC |
| **S07, S08** | U | UC | None | UT | TC | T | UTC | C |
| **S09, S10** | T | UTC | TC | UC | None | U | C | UT |
| **S11, S12** | C | None | UT | T | UTC | TC | U | UC |
| None-No Tools (Baseline) U-URET T-TMA C-CPDLC | | | | | | | | |

## 3. Results

We present the results of the experiment in a series of graphs depicting the means of the eight tool conditions for all participants. For most of the measures, we present the means separately for the R-side and D-side; however, in some cases, we show R-side/D-side team means. The graphs also depict error bars for each mean representing +/- 1 standard error of the mean as an indicator of between-subject or between-team variability. We used the following formula for computing the standard error.

Standard Error = Standard Deviation / Square Root (N), where N is the number of observations used to compute the mean, (i.e., 6 R-side participants, 6 D-side participants, or 6 teams)

We used inferential statistics to analyze the data using two different approaches. In the first approach, we performed a 2-way analysis of variance (ANOVA) on each dependent measure with Position (R-side, D-side) as a between-subjects factor and Tools (None, U, T, C, UT, UC, TC, UTC) as a repeated measures factor. For the measures that produced team data, we performed a 1-way ANOVA on the Tools factor. This first approach allowed us to analyze the data in terms of differences between the tool conditions. A significant interaction between the factors would indicate that the trends were different for the two controller positions.

In the second approach, we analyzed the R-side and D-side data separately in two different 3-way ANOVAs with URET (Absent, Present), TMA (Absent, Present), and CPDLC (Absent, Present) as repeated measures factors. For the measures that produced team data, we performed only one 3-way ANOVA. This second approach allowed us to analyze the data in terms of the impact of each tool. A significant interaction between the tools would indicate a potential collocation issue. In each ANOVA for both approaches, the standard significance level was $p < .05$. When there were significant effects, we performed Tukey HSD post hoc comparisons to determine the means that were different using a group comparisons significance level of $p < .05$.

### 3.1 Objective #1: Assess whether controllers have access to information when needed and whether they interpret available information correctly

We examined controller ratings of whether they were able to quickly access needed information or whether the collocation of tools made access to information difficult. We also conducted structured group debriefings with controllers to discuss any information access issues that occurred during simulation and why they may have occurred. Finally, our SMEs made ratings and comments about their observations on how controllers were using the tools during the simulation to further clarify any information access issues.

Figure 2 shows controller ratings for how often CPDLC caused display clutter on both the R-side and D-side displays for each of the four tool conditions with CPDLC operational. R-side and D-side controller ratings were different depending upon the tools in use, [Position x Tools interaction: $F(3,30) = 4.36$, $p = .012$]. For the R-side, controller ratings were rather low indicating that they did not think CPDLC caused clutter very often. For the D-side, controller ratings varied from low to moderate depending upon the tools displayed, [D-side, Tools simple main effect: $F(3,15) = 4.03$, $p = .027$]. When CPDLC was displayed alone and when CPDLC and TMA were displayed together, ratings of display clutter were very low. Ratings were much higher when CPDLC and URET were both displayed and when all three tools were displayed together (confirmed by Tukey HSD comparisons).

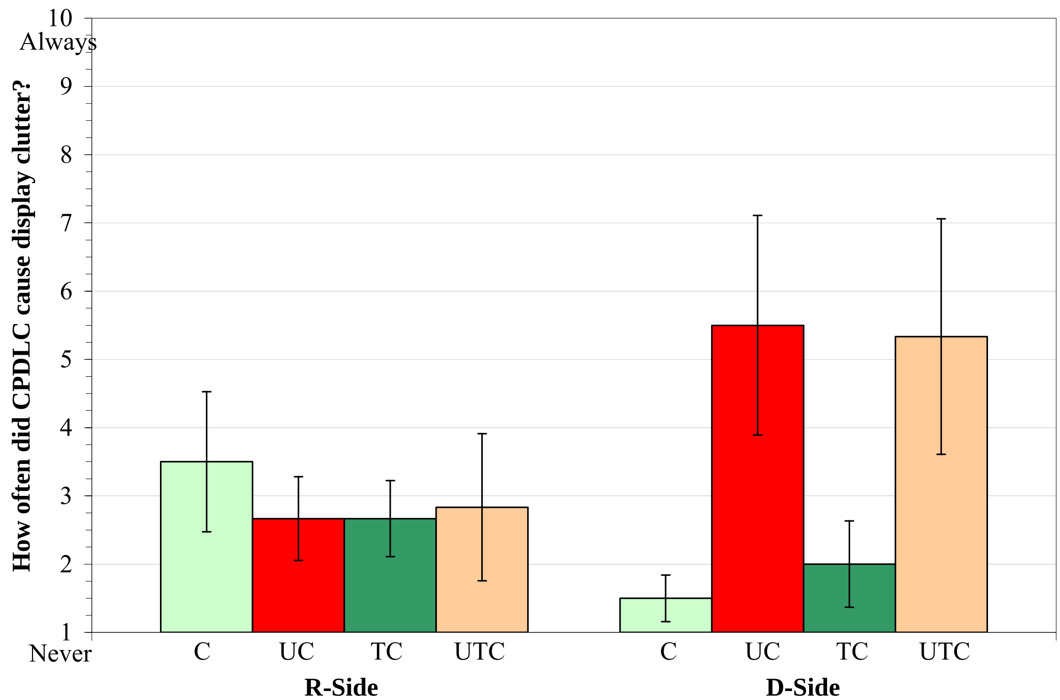


Figure 2. Mean controller ratings for how often CPDLC caused display clutter provided by the R-side and D-side positions for each of the CPDLC tool conditions.

Figure 3 shows controller ratings for how often URET caused display clutter on the D-side display for each of the four tool conditions with URET operational. In this case, D-side controller ratings were rather low indicating that they did not think URET caused clutter on the D-side display whether used alone or in combination with TMA and CPDLC. The D-side controllers in our study were used to operating URET alone at their facility. This may have influenced their choice in identifying CPDLC as the source of display clutter with their ratings, not URET.

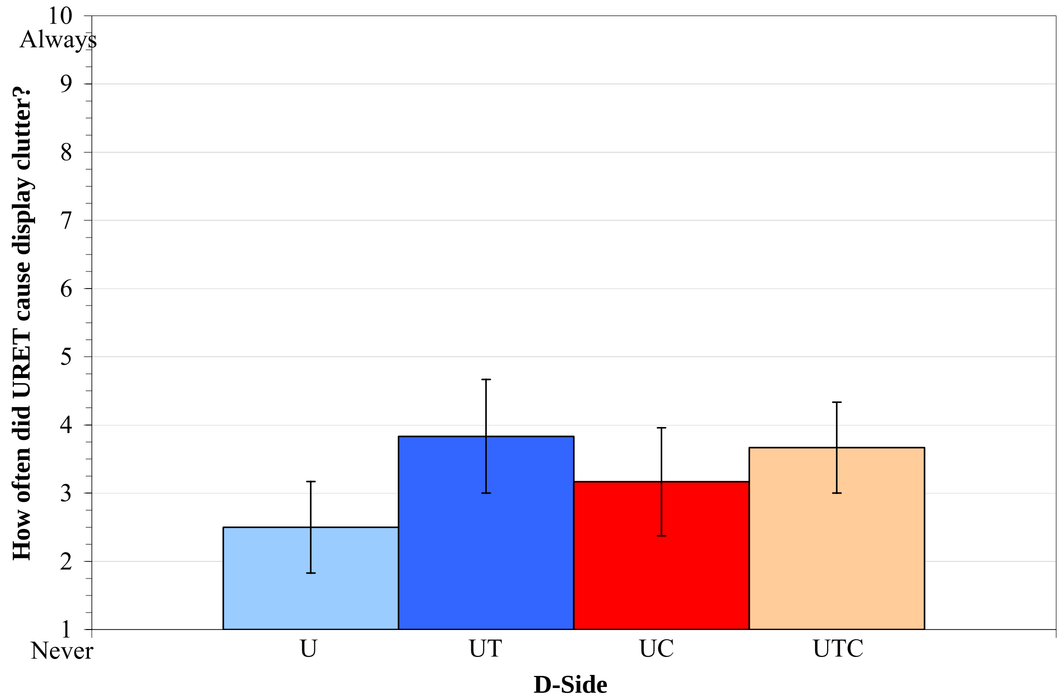


Figure 3. Mean controller ratings for how often URET caused display clutter provided by the D-side position for each of the URET tool conditions.

In our group discussions, controllers frequently commented that when URET and CPDLC were collocated on the D-side, there was display clutter. Figure 4 illustrates this issue and shows a typical configuration of URET and CPDLC on the D-side display. Controllers expand the URET Aircraft List to cover most of the display so that as much aircraft information can be seen as possible. The CPDLC Message Out and Menu Text windows are shown along with the D-side CRD. URET and CPDLC windows overlap each other because in this study there was no integration of the information displays for different tools. The URET Aircraft List can be resized and made smaller, but controllers do not often do this because important information would be truncated from the window and would not be visible on the display.

Figure 5 illustrates what happens on the D-side display during typical use of URET and CPDLC. When a controller selects the URET Aircraft List as the active window, it becomes front and the CPDLC windows move to the back and become covered. In this configuration, updated information in the CPDLC Message Out window is not visible to controllers.

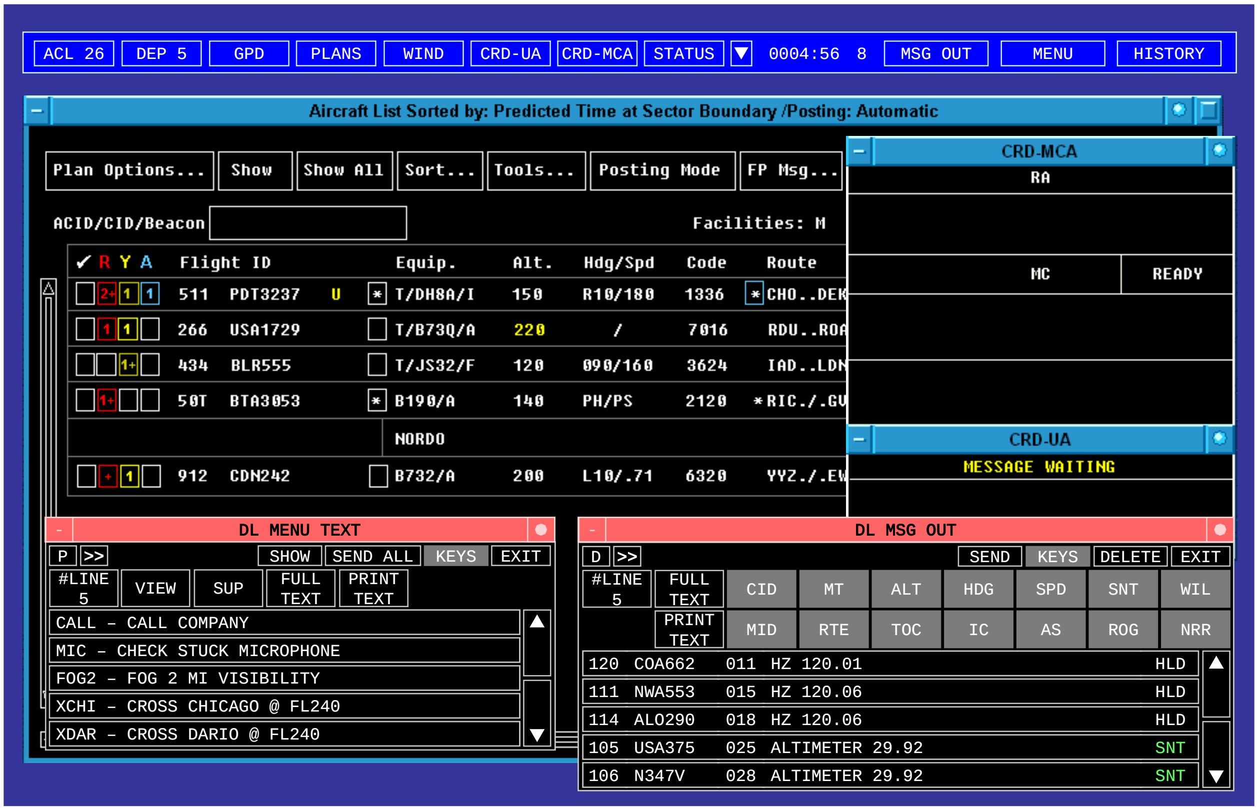


Figure 4. Typical configuration of URET and CPDLC on the D-side display.

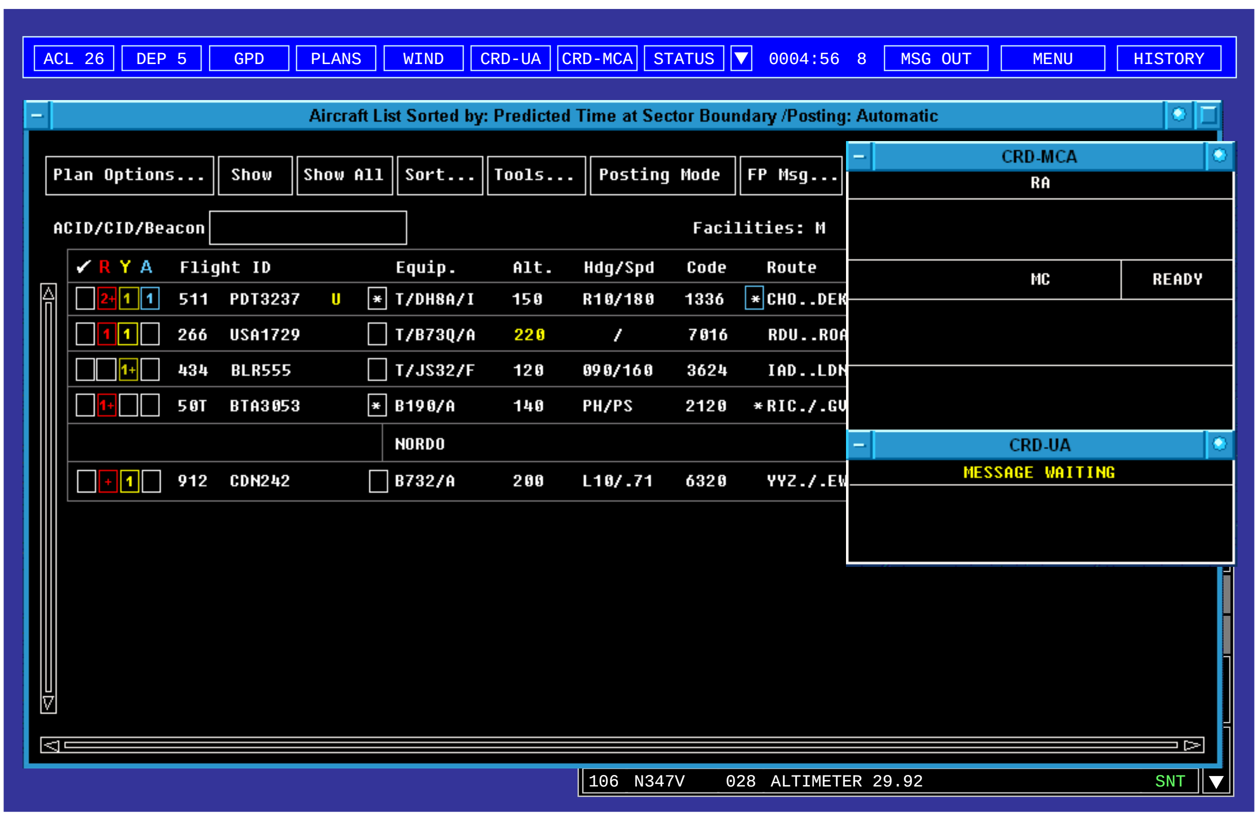


Figure 5. URET aircraft list covering CPDLC windows on the D-side display.

In our group discussions, some controllers commented that they wanted TMA delay time information available on the D-side display. In the simulation, controllers positioned the TMA list in a location near the edge of the DSR where D-side controllers could see the information. The participants commented that the R-side should be able to position the TMA list wherever is most convenient for him/her and that D-side controllers should have access to this information on the D-side display. During the simulation, one controller used the URET Aircraft List Special Emphasis Area to sort arrival aircraft in the same order as the TMA list. This controller commented that having arrival aircraft sorted in this manner helped with monitoring their status. Also, it would be even better if TMA delay time information was available on the URET Aircraft List. Finally, controllers commented that they were concerned about adding to the clutter on the D-side display, but thought there should be a smart way to show TMA information without causing more clutter. Therefore, despite the already cluttered display, controllers thought it was important to have access to key information about all of the tools on the D-side display.

Observer ratings and comments supported the idea that TMA delay time information was very important to both R-side and D-side controllers and influenced controller overall prioritization of tasks. Figure 6 shows mean observer ratings of controller overall prioritization effectiveness for controller teams for each of the eight tool conditions. The observers rated controller prioritization as slightly less effective when TMA was operational [TMA effect: $F(1,5) = 12.00$, $p = .018$]. The observers commented that controllers were paying a great deal of attention to the TMA List which made them fall behind on other tasks like accepting handoffs.

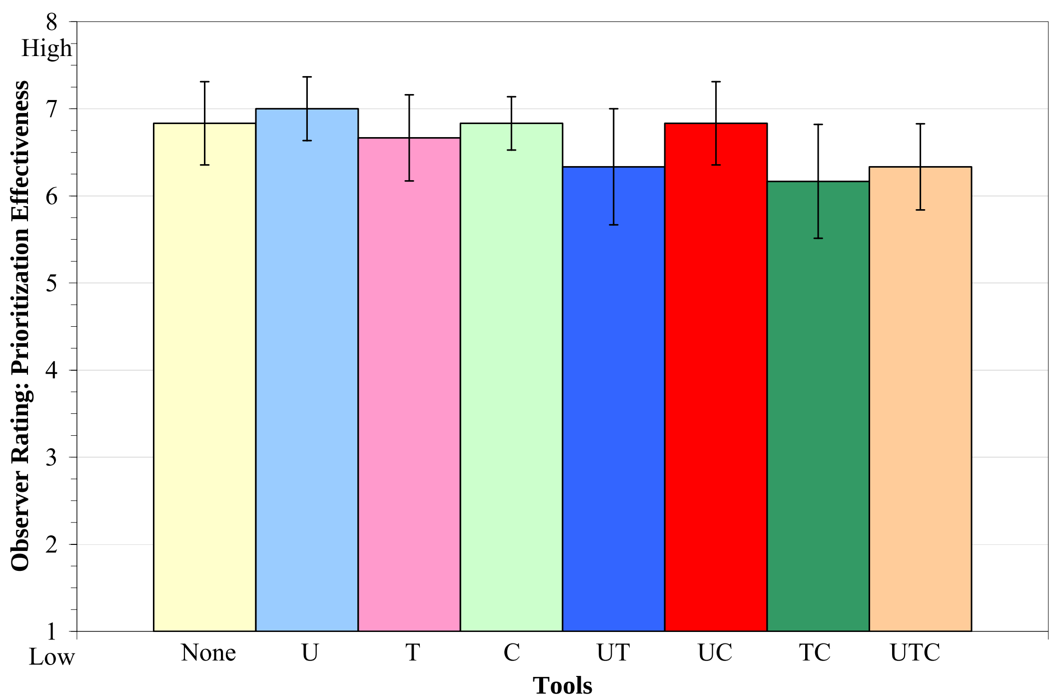


Figure 6. Mean observer ratings of overall prioritization effectiveness for controller teams for each of the tool conditions.

3.2 Objective #2: Assess R-side/D-side Roles and Responsibilities

For this report, we were interested in the number of CPDLC TOC messages sent by R-side and D-side controllers to describe the roles and responsibilities for CPDLC usage during the simulation. We did not create a procedure for which team member should send CPDLC TOCs to aircraft. Therefore, this measure indicated how controllers decided for themselves which team member would send CPDLC TOC messages when different tools were operational.

Figure 7 shows the mean number of CPDLC TOC messages sent by the R-side and D-side positions for each of the four tool conditions with CPDLC operational. The R-side sent from 90% to 95% of the CPDLC TOC messages in each of the tool combinations [Position effect: $F(1,10) = 194.96$, $p < .001$]. Therefore, the R-side retained the responsibility to issue the change of frequency to aircraft.

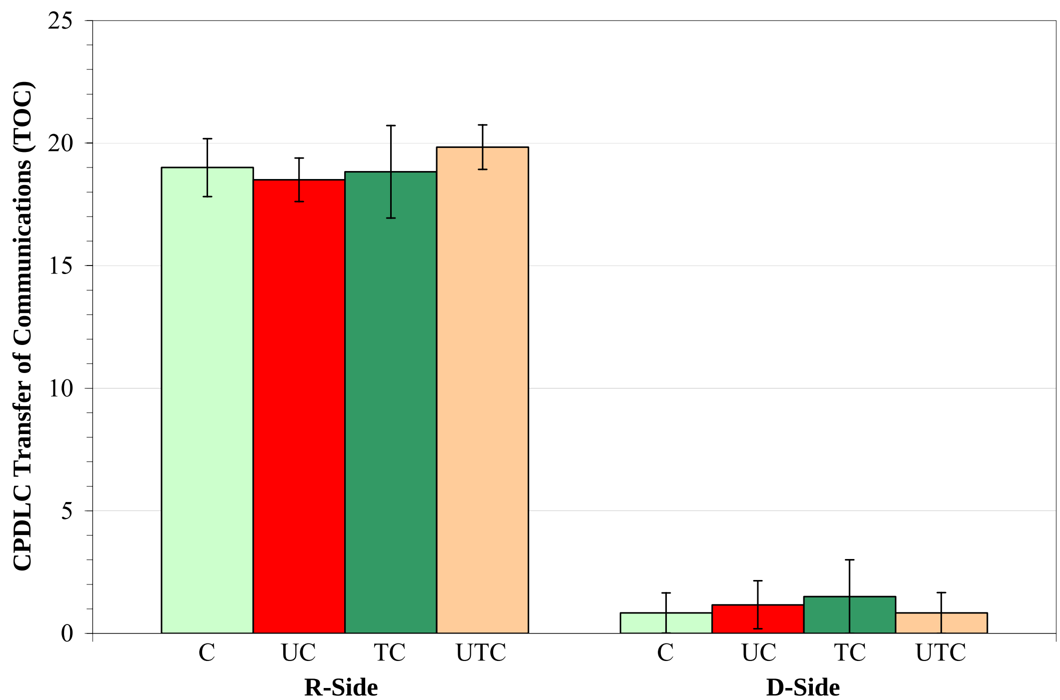


Figure 7. Mean number of CPDLC TOC messages sent by R-side and D-side for each of the CPDLC tool conditions.

In our group discussions, controllers commented that the R-side and D-side were frequently not aware of the CPDLC messages sent by each other and received by pilots. There was no auditory feedback while using CPDLC, therefore, controllers had to visually monitor the CPDLC Message Out window to know when their team member sent a message or verbally coordinate with each other when messages were sent. This may become a multi-tool issue when one controller sends a CPDLC TOC message early and, based on URET or TMA information, the other team member decides to take (or recommends) action on the aircraft.

3.3 Objective #3: Assess R-side/D-side Workload and Situational Awareness

We examined controller ATWIT and NASA-TLX ratings as direct subjective measures of workload and number of ground-to-air voice transmissions and airspeed, heading, and altitude changes as indirect objective measures of workload. High workload ratings when multiple tools are operational would be a warning signal that indicates a collocation issue. Large increases in ground-to-air transmissions or airspeed, heading, and altitude changes when more than one tool is in use would indicate a collocation issue. We also examined controller SA ratings to identify any decrease in SA that would indicate a collocation issue when the tools are used together.

Figure 8 shows mean ATWIT workload ratings provided by the R-side and D-side positions for each of the eight tool conditions. For the R-side, ATWIT ratings were moderate and there were few differences between the tool combinations. For the D-side, ATWIT ratings were low to moderate and tended to differ for different tool combinations. D-side ATWIT ratings were the lowest in the baseline condition without any tools; however, this was not statistically significant. We must emphasize that 5 of the 6 controller teams did not want to use flight strips during the simulation. Therefore, workload for this baseline condition may have been lower than actual field conditions where flight strips are actively used. Ratings tended to increase slightly in the single tool conditions and further increase in the two and three tool combinations. An additional analysis indicated that D-side controller ratings were the highest in conditions where URET was operational [D-side, URET effect: $F(1,5) = 13.39$, $p = .015$].

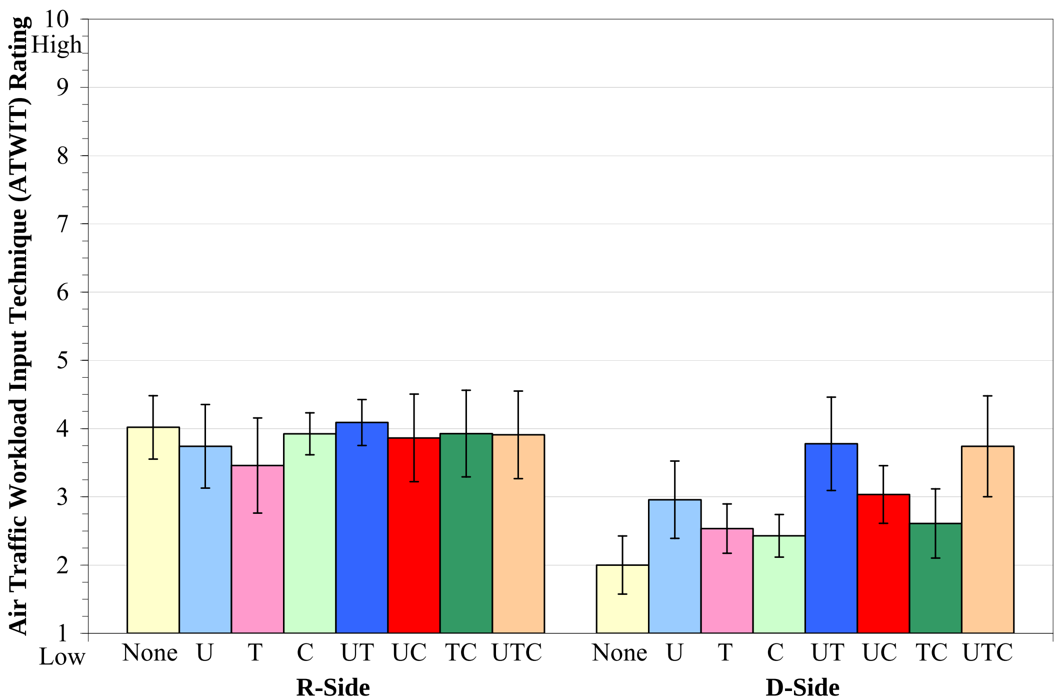


Figure 8. Mean ATWIT workload ratings provided by the R-side and D-side positions for each of the tool conditions.

Figure 9 shows mean NASA-TLX mental demand workload ratings provided by the R-side and D-side positions for each of the eight tool conditions. For the R-side, mental demand ratings were moderate and there were few differences between the tool combinations. For the D-side, mental demand ratings were low to moderate and tended to differ for different tool combinations. For both R-side and D-side, mental demand ratings were the lowest in the baseline condition without any tools, [Tools effect: $F(7,70) = 2.54$, $p = .022$]. However, the only statistically significant difference was between the no tools condition and the TMA-CPDLC combination (confirmed by Tukey HSD comparisons). Again, D-side workload ratings may have been higher in the No Tools condition if controllers had used flight strips as they do in actual field conditions. Ratings tended to increase slightly in the single tool conditions and greatly increase in the two and three tool combinations. An additional analysis indicated that D-side controller ratings were the highest in conditions where CPDLC was operational [D-side, CPDLC effect: $F(1,5) = 7.50$, $p = .041$].

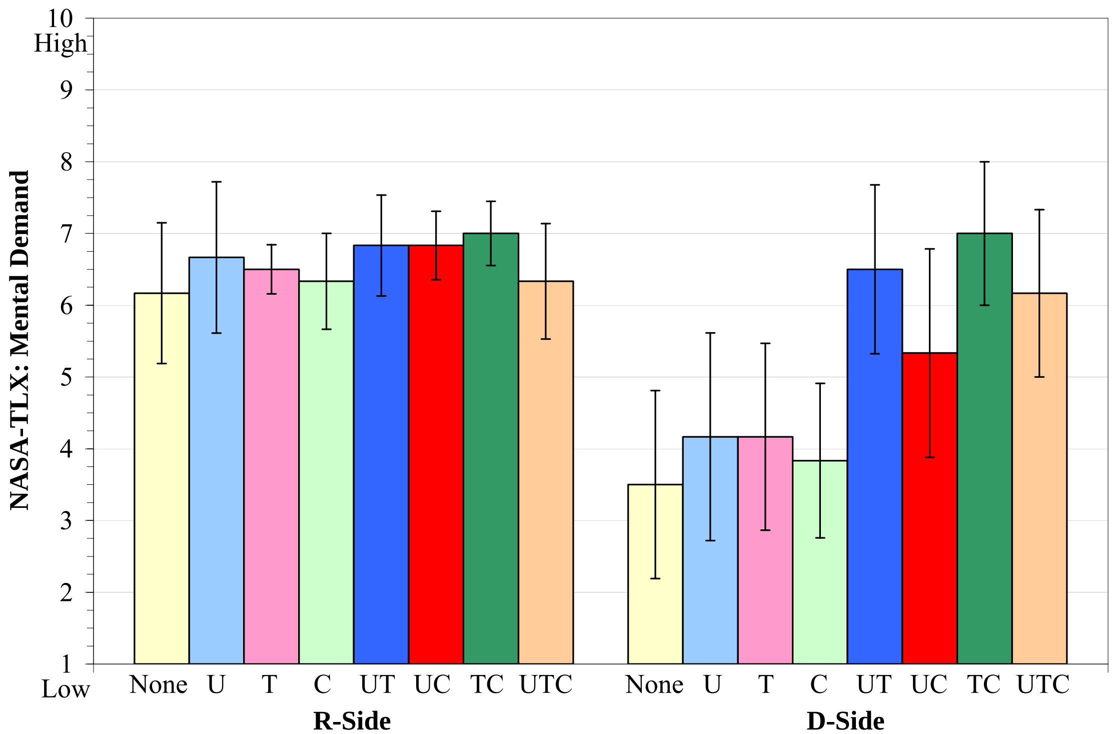


Figure 9. Mean NASA-TLX mental demand workload ratings provided by the R-side and D-side positions for each of the tool conditions.

Figure 10 shows the mean number of ground-to-air transmissions made by the R-side controller for each of the eight tool conditions. Controllers made 9.59% fewer ground-to-air transmissions when CPDLC was operational [CPDLC effect: $F(1,5) = 165.40$, $p < .001$]. This result was expected because CPDLC was designed to decrease ground-to-air voice transmissions. Fewer ground-to-air transmissions were expected when CPDLC was used alone and also when it was collocated with other tools. Therefore, this result did not indicate a collocation issue when CPDLC was used with other tools.

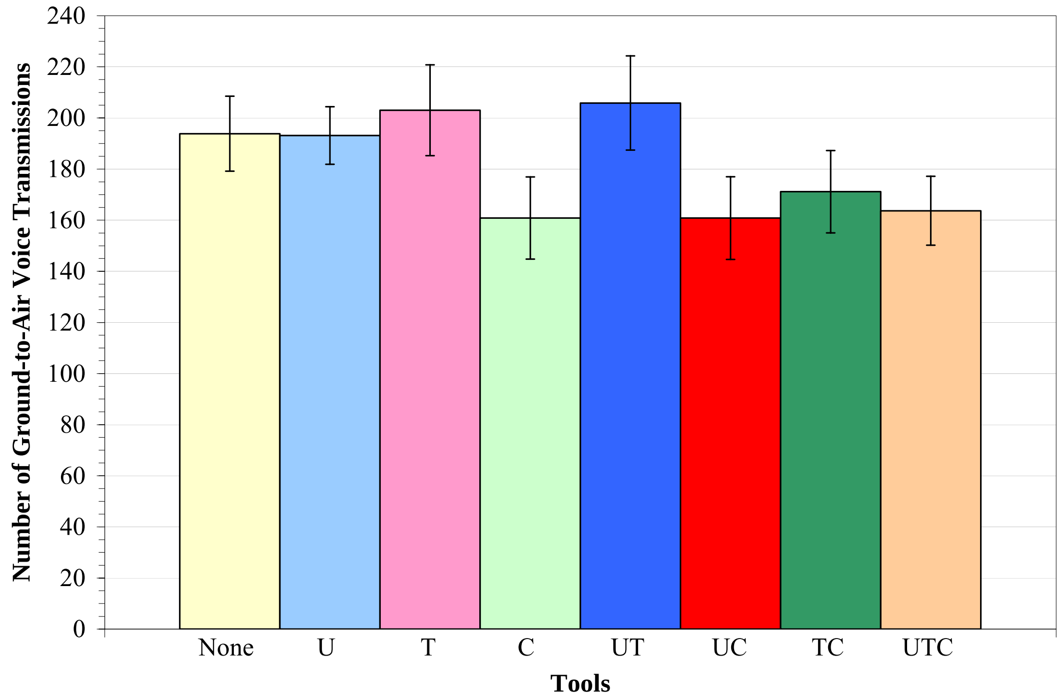


Figure 10. Mean number of ground-to-air transmissions made by the R-side controller for each of the tool conditions.

Figure 11 shows the mean number of airspeed changes made by the R-side controller for each of the eight tool conditions. Controllers made 22.35% more airspeed changes when TMA was operational [TMA effect: $F(1,5) = 14.45$, $p = .013$]. This result was expected because controllers frequently used airspeed changes as a control technique to meet TMA metering times. More airspeed changes were expected when TMA was used alone and also when it was collocated with other tools. Therefore, this result did not indicate a collocation issue when TMA was used with other tools.

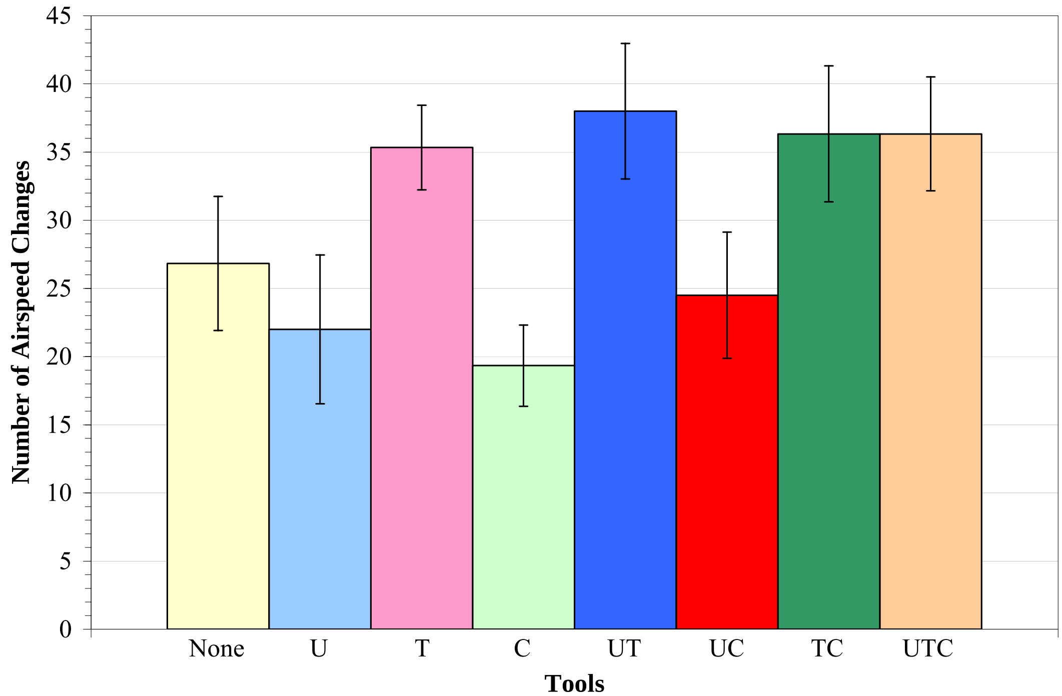


Figure 11. Mean number of airspeed changes made by the R-side controller for each of the tool conditions.

In addition, we examined the mean number of heading and altitude changes made by the R-side controller for each of the tool combinations. The results indicated that there were no differences in either heading or altitude changes between the tool combinations. Controllers made very few heading changes during the simulation because vectoring was not necessary to meet TMA metering times or miles-in-trail restrictions. Also, controllers used altitude changes to descend landing aircraft, but not to meet TMA metering times or miles-in-trail restrictions.

Figure 12 shows mean SA ratings made by the R-side and D-side positions for each of the eight tool conditions. In general, controller SA ratings were very high. For the R-side, ratings were the highest when URET alone was operational and the lowest in the four conditions where CPDLC was operational. For the D-side, ratings were the highest when URET alone was operational and the lowest in the condition where URET and CPDLC were combined; however, these trends were not statistically significant.

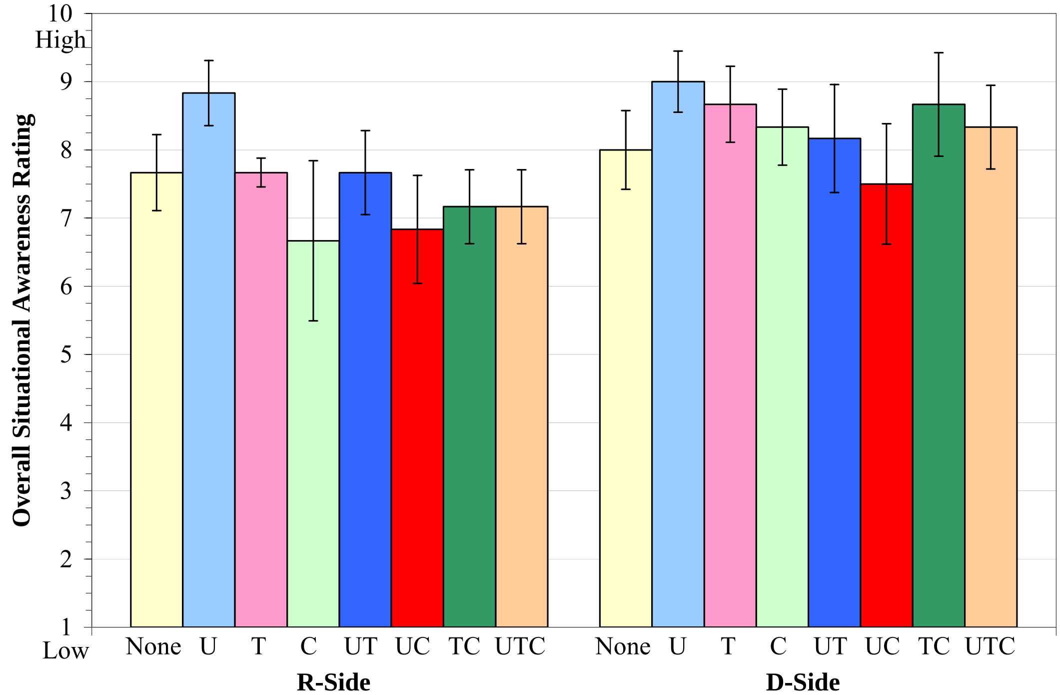


Figure 12. Mean SA ratings made by the R-side and D-side positions for each of the tool conditions.

3.4 Objective #4: Access R-side/D-side Teamwork and Communications

We examined the number of handoffs accepted and initiated by R-side and D-side controllers to describe controller teamwork during the simulation. These measures indicated how controllers decided which team member would accept and initiate handoffs when different tools were operational. We used these measures to determine if there were any changes in the way team members interacted with each other with additional tools. Also, we examined the number of flight plan readouts to assess controller needs for flight plan data when different tools were operational. We will examine controller communications between R-side and D-side team members in more detail in a future report.

Figure 13 shows the mean number of handoffs accepted by the R-side and D-side positions for each of the eight tool conditions. The R-side accepted more than twice as many handoffs as the D-side [Position effect: $F(1,10) = 30.31$, $p < .001$]. However, there were no differences in the number of handoffs accepted with different tool combinations. Therefore, the R-side retained the majority of the handoff duties.

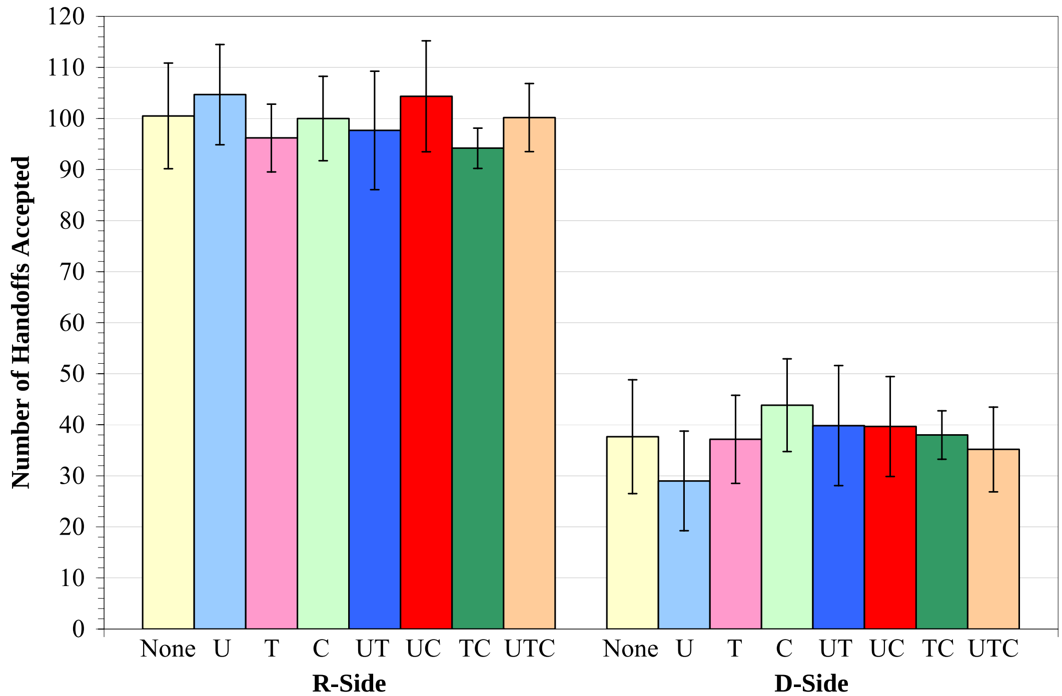


Figure 13. Mean number of handoffs accepted by the R-side and D-side positions for each of the tool conditions.

Figure 14 shows the mean number of handoffs initiated by the R-side and D-side positions for each of the eight tool conditions. In general, the D-side initiated the majority of the handoffs; however, this trend was not statistically significant. Also, there were no differences in the number of handoffs initiated with different tool combinations.

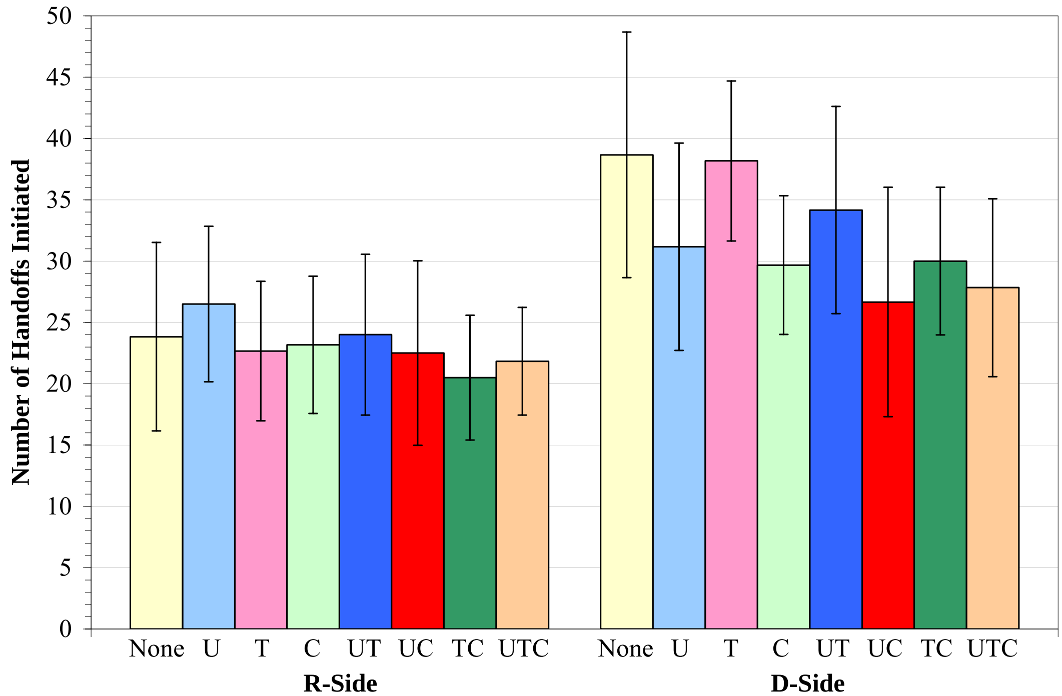


Figure 14. Mean number of handoffs initiated by the R-side and D-side positions for each of the eight tool conditions.

Figure 15 shows the mean number of flight plan readouts by the R-side and D-side positions for each of the eight tool conditions. R-side and D-side number of flight plan readouts were different depending upon the tools in use, [Position x Tools interaction: $F(7,70) = 4.61$, $p < .001$]. The R-side controller performed some flight plan readouts, but there were no differences between the tool combinations. The D-side controller performed a different number of flight plan readouts depending upon the tool combination, [D-side, Tools simple main effect: $F(7,35) = 7.64$, $p < .001$]. The D-side controller made the most flight plan readouts in the No Tools condition and the least number of flight plan readouts in the four conditions where URET was operational (confirmed by Tukey HSD comparisons). An additional analysis indicated that D-side controllers made the fewest flight plan readouts when URET was operational [D-side, URET effect: $F(1,5) = 12.82$, $p = .016$]. This result was expected because D-side controllers did not need to perform flight plan readouts when URET was operational because URET provided the flight data for aircraft.

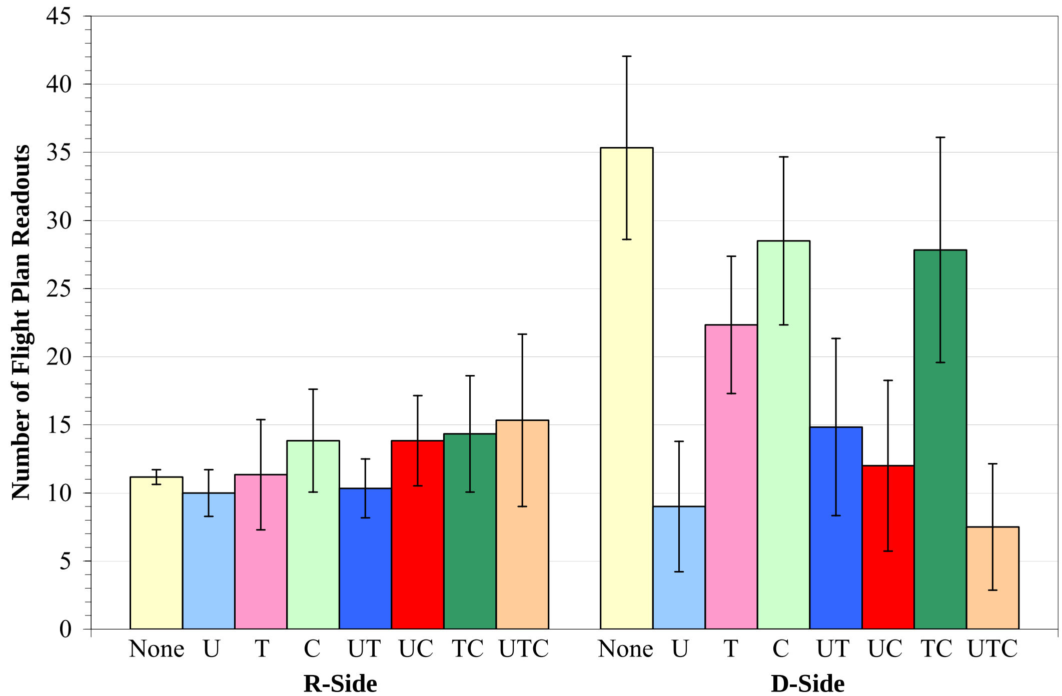


Figure 15. Mean number of flight plan readouts by the R-side and D-side positions for each of the eight tool conditions.

3.5 Other Measures

3.5.1 System Effectiveness Measures

Figure 16 shows the mean flight distance per aircraft for controller teams for each of the eight tool conditions. In general, flight distance per aircraft was the longest in the No Tools condition and at least slightly shorter in each of the conditions with tools; however, these trends were not statistically significant.

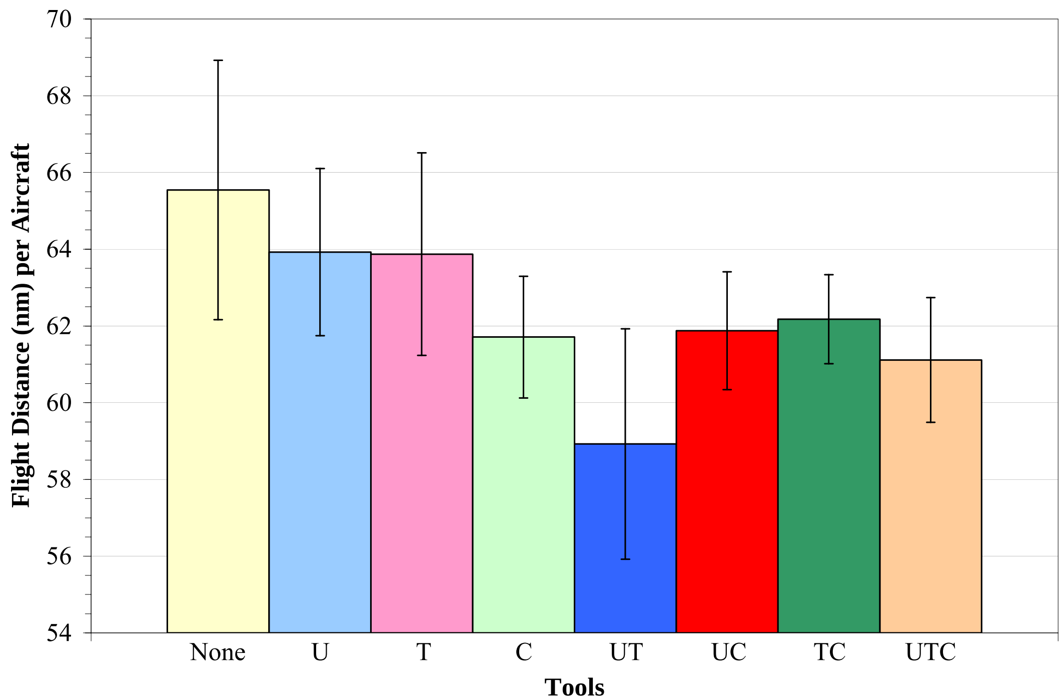


Figure 16. Mean flight distance per aircraft for controller teams for each of the tool conditions.

In addition, we examined the mean flight time per aircraft for controller teams for each of the eight tool conditions. The pattern of data for mean flight time was similar to mean flight distance per aircraft. Flight time per aircraft was the longest in the No Tools condition and at least slightly shorter in each of the conditions with tools; however, these trends were not statistically significant.

There were two cases where aircraft lost separation during the entire experiment. In the first loss-of-separation, CPDLC was the only tool in operation. The controllers were establishing an arrival sequence with two aircraft when they lost separation. The controllers were aware that the distance was going to be close with the aircraft, but they thought they had enough separation. In the second loss-of-separation, TMA and CPDLC were operational. The D-side pointed out the aircraft conflict to the R-side. The R-side attempted to separate the aircraft with heading changes to one of the aircraft, but didn't turn the aircraft sharp enough to ensure separation. In both cases where there was loss-of-separation, the closest-point-of-approach was over 4 nm.

3.5.2 Exit Questionnaire Ratings

Table 7 shows the controller ratings of simulation realism. In general, controllers rated the simulation realism as moderate. Controller mean ratings ranged from 4.20 to 7.67 on a 10-point scale depending upon the specific aspect of the simulation. The lowest realism rating was for the TMA implementation. Controllers who were experienced with TMA commented that the delay times generated in our simulation were not realistic. In field operations, typical TMA delay times are positive and are often resolved by slowing aircraft. In our simulation, TMA delay times were frequently small and sometimes negative, which made controllers increase aircraft airspeeds. This discrepancy in TMA operation may have affected some measures like aircraft flight distance, flight time, and airspeed changes. However, controllers commented that it did not have a major impact on identifying tool collocation issues.

Lastly, controllers rated the ATWIT workload rating technique as low in interference, (*Mean* = 1.60, *SD* = 0.84), where 1 = no interference at all and 10 = a great deal of interference.

Table 7. Controller Ratings of Simulation Realism

| Question | Extremely Unrealistic | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely Realistic |
|---|---|---|---|
| Rate the realism of the overall simulation experience compared to actual ATC operations. | Mean = 6.20 | SD = 1.75 | Range (4 – 9) |
| Rate the realism of the simulation URET implementation compared to actual field operation. | Mean = 5.60 | SD = 2.30 | Range (2 – 8) |
| Rate the realism of the simulation TMA implementation compared to actual field operation. | Mean = 4.20 | SD = 2.39 | Range (1 – 7) |
| Rate the realism of the simulation CPDLC emulation compared to actual field operation. | Mean = 7.67 | SD = 2.08 | Range (6 – 10) |
| Rate the realism of the simulation DSR hardware compared to actual DSR equipment. | Mean = 7.00 | SD = 2.31 | Range (3 – 10) |
| Rate the realism of the simulation DSR software compared to actual DSR functionality. | Mean = 6.80 | SD = 1.69 | Range (4 – 9) |
| Rate the realism of the simulation generic airspace compared to actual NAS airspace. | Mean = 7.60 | SD = 1.78 | Range (5 – 10) |
| Rate the realism of the simulation traffic scenarios compared to actual NAS traffic. | Mean = 7.20 | SD = 1.32 | Range (5 – 9) |

4. Discussion

The RDHFL ATC simulator collects a very large set of raw data about what controllers do in simulation. This report presents a quick look at data we could readily access and quickly summarize to provide timely answers to important research issues concerning the collocation of URET, TMA, and CPDLC.

The most important collocation issue identified in this experiment was that controllers had difficulty accessing important information on the D-side display when URET and CPDLC were both operational (i.e., display clutter). Controller ratings indicated the cause of this display clutter problem was CPDLC displays on the D-side monitor. They did not identify URET displays as causing display clutter. All the D-side controllers were experienced URET users and none had worked with CPDLC prior to the simulation; therefore, it is not surprising that these controllers would attribute the display clutter to CPDLC and not URET. Also, controller ratings indicated that neither URET alone nor CPDLC alone caused D-side display clutter. Finally, R-side controller ratings indicated that CPDLC caused very little display clutter on the DSR display.

It is important to note the controllers identified this display clutter problem using the D-side CPDLC CHI we developed in the RDHFL for use in this simulation study. We designed the D-side CHI to be consistent with a “stovepipe” independent deployment of the tools with simple features to help controllers manage the multiple windows associated with each tool. Members of the CPDLC users group helped us develop the D-side CHI. We then asked the ATDET to review the interface for use in this study. However, this specific D-side CHI was not intended to be the interface that will be deployed to ARTCCs in the future.

Another collocation issue identified in this experiment was that D-side controllers had to access TMA delay time information on the R-side display. In the simulation, controllers positioned the TMA list in a location near the edge of the DSR where D-side controllers could see the information. Both controllers spent a great deal of time viewing the TMA list. Controllers thought it was important to have TMA information available on the D-side display where it could be more easily accessed by D-side controllers. One controller used the URET Aircraft List Special Emphasis Area to sort arrival aircraft in the same order as the TMA list. However, controllers were concerned that simply showing the TMA list on the D-side might add to the D-side display clutter.

Good human factors design principles prescribe that users must have immediate access to important information and that critical information should never be covered. A “stovepipe” independent deployment of these tools will result in impaired access to timely information. The results of this study indicated that better human factors efforts should be made towards integrating the information from URET, TMA, and CPDLC. Even if these systems cannot be entirely integrated, we should explore integrating the displays on the D-side monitor prior to deployment.

The number of CPDLC TOC messages indicated that R-side controllers sent most of the TOCs. There were no mandatory procedures for using CPDLC by the R-side and D-side in our simulation. We allowed each controller team to practice together and decide for themselves who would send the CPDLC TOCs to aircraft. Although the results indicated that D-side controllers did not use the TOC service very often, controllers still expressed concerns about not knowing what their team member was doing with CPDLC. Unlike voice communications, there were no audible cues with CPDLC to help controllers maintain situational awareness of their team member's actions. Controllers had to visually monitor the CPDLC Message Out window to know when their team member sent a TOC message. If the CPDLC display was covered by URET, the D-side controller could miss a sent message. In addition, CPDLC messages were visible in the Message Out window for only a few seconds after a pilot "Wilcox" was received. Therefore, controllers had to be very vigilant. An even greater concern for safety exists if CPDLC is used to issue control instructions (e.g., altitude, heading or airspeed future services). D-side controllers could recommend actions that create aircraft conflicts when they are not aware of the CPDLC messages sent. More research needs to be conducted examining the potential risks, roles, and responsibilities for CPDLC usage, especially when other tools are being used.

Controller workload ratings using ATWIT and NASA-TLX indicated that D-side workload and mental demand tended to increase when two and three tools were operational. However, D-side workload ratings were only moderate and never reached an excessively high level. We designed the scenarios with moderate traffic levels so that controllers would not be overwhelmed with traffic and stop using the tools. We thought moderate traffic levels would allow controllers to use the tools more often and better identify any collocation issues. However, the results of this experiment may have been different with higher traffic levels and greater workload demands on controllers.

D-side controller workload was rather low in the baseline condition without any tools. Workload for this baseline condition may have been lower than actual field conditions where flight strips are actively used because 5 of the 6 controller teams did not want flight strips posted at their sector. All of our D-side controllers came from URET facilities that do not require flight strips. The baseline condition was intended to be an experimental comparison for the conditions with tools. Without flight strips, controllers used flight plan readout to obtain aircraft routing information. Finally, R-side ATWIT and NASA-TLX ratings indicated that controller workload and mental demand were only moderate and did not change with tool use.

We used the number of ground-to-air voice transmissions and airspeed, heading, and altitude changes as additional indicators of controller workload. As expected, controllers made fewer ground-to-air voice transmissions when CPDLC was operational. Also, as expected, controllers made more airspeed changes when TMA was operational because controllers frequently used airspeed changes to meet metering times. However, there were no differences in ground-to-air transmissions or airspeed, heading, and altitude changes when tools were used in combination. Therefore, the changes in these measures were due to each tool's expected effect and not due to collocation.

Finally, controllers rated their SA as very high and did not vary with different tool combinations. Although sometimes self-ratings can potentially misrepresent true SA, there was no indication that this actually occurred during the simulation. With the exception of two cases where aircraft separation was lost, controllers maintained safety throughout the scenarios. In both cases, controllers were aware of the loss of aircraft separation. For the present study, we used self-ratings of SA as a technique to elicit controller concerns and identify collocation issues for group discussion.

## 5. Conclusion

The purpose of this simulation study was to identify collocation issues when URET, TMA, and CPDLC were implemented together at the same sector. In a high fidelity HITL simulation, the main concern was D-side display clutter when URET and CPDLC were being used together. Another concern was the need for TMA information on the D-side display without adding to the display clutter. In addition to identifying these important display issues, controllers provided some ideas that could resolve these problems. From a human factors perspective, URET, TMA, and CPDLC should be integrated on the D-side display. This solution avoids the problem of multiple windows or displays that were a consequence of the "stovepipe" implementation of these tools in our simulation. With URET, TMA, and CPDLC information integrated, controllers should have easier access to information when needed without having to monitor and manage multiple displays.

Controllers also provided some non-integration ideas including a larger D-side display and an improved D-side CHI that would make it easier to manage multiple information displays. Although there would appear to be advantages to all of these ideas, there may also be pitfalls that can only be assessed in an HITL simulation. Therefore, we recommend that more research be conducted to investigate URET, TMA, and CPDLC collocation issues and potential solutions. Future simulations should examine the best presentation of the information, specific procedures for R-side and D-side tool use, and higher traffic levels for scenarios.

In this report, we presented the first of three experiments that examined human factors issues in the collocation of URET, TMA, and CPDLC. In subsequent reports, we will present the two additional experiments and address teamwork and communications issues with the collocation of these tools. In addition, we will examine human factors issues related to using the three tools with an R-side only staffing configuration. Finally, we will also examine eye tracking data from the R-side position to explore the information controller's access when these tools are in use.

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## Acronyms

| | |
|---|---|
| ANOVA | Analysis of Variance |
| ARTCC | Air Route Traffic Control Center |
| AS | Altimeter Setting |
| ATC | Air Traffic Control |
| ATCS | Air Traffic Control Specialist |
| ATDET | Air Traffic Design Evolution Team |
| ATWIT | Air Traffic Workload Input Technique |
| CCLD | Core Capability Limited Deployment |
| CHI | Computer Human Interface |
| CPDLC | Controller-Pilot Data Link Communications |
| CRD | Computer Readout Display |
| CTAS | Center TRACON Automation System |
| D-side | Data (or Radar Associate) Controller Position |
| DESIREE | Distributed Environment for Simulation, Rapid Engineering, and Experimentation |
| DSR | Display System Replacement |
| FAA | Federal Aviation Administration |
| FL | Flight Level |
| HITL | Human-In-The-Loop |
| IC | Initial Contact |
| MT | Menu Text |
| NAS | National Airspace System |
| NASA | National Aeronautics and Space Administration |
| NATCA | National Air Traffic Controller Association |
| R-side | Radar Controller Position |
| RDHFL | Research Development and Human Factors Laboratory |
| SA | Situational Awareness |
| SME | Subject Matter Expert |
| TGF | Target Generation Facility |
| TLX | Taskload Index |
| TMA | Traffic Management Advisor |
| TOC | Transfer of Communications |
| URET | User Request Evaluation Tool |
| WJHTC | William J. Hughes Technical Center |

APPENDIX A

Informed Consent Form

I, ______________________________, understand that this study, entitled "Human-in-the-Loop Evaluation of the Collocation of User Request Evaluation Tool (URET), Traffic Management Advisor (TMA), and Controller-Pilot Data Link Communications (CPDLC)" is sponsored by the Federal Aviation Administration and is being directed by Dr. Randy Sollenberger.

**Nature and Purpose:**

I have been recruited to volunteer as a participant in this project. The purpose of the study is to identify the human factors issues of collocating URET, TMA, and CPDLC in a high-fidelity, controller-in-the-loop simulation. The researchers will use the results of this study to provide guidance for deploying the three support tools in the field.

**Experimental Procedures:**

Participants will arrive at the simulation laboratory in groups of four controllers for each two-week session. For most of the simulation, controllers will work in R-side/D-side teams without changing positions. However, all participants will work two scenarios as an R-side controller without D-side assistance. The first week of the simulation will consist of a project briefing, airspace familiarization, support tool training, and practice scenarios. Participants will stay over the weekend. The second week of the simulation will consist of twelve 45-minute test scenarios and an exit debriefing. Participants will work from 8:00 AM to 4:30 PM each day with a rest break after each scenario and a lunch break.

Participants will control traffic while using different combinations of support tools. After each scenario, the controllers will complete questionnaires to evaluate the impact of the tools on controller performance, workload, and situational awareness. In addition, subject-matter experts will make over-the-shoulder observations during the simulation to further assess aspects of the impact of the support tools. Finally, an automated data collection system will record system operations and generate a set of standard ATC simulation measures, which include safety, capacity, efficiency, and communications measures. The simulation will be audio-video recorded in case researchers need to re-examine any important simulation events.

**Discomfort and Risks:**

I understand that I will not be exposed to any foreseeable risks or intrusive measurement techniques.

**Confidentiality:**

My participation is strictly confidential, and no individual names or identities will be recorded or released in any reports.

**Benefits:**

I understand that the only benefit to me is that I will be able to provide the researchers with valuable feedback and insight into the impact of using different support tools. My data will help the FAA to identify the human factors issues of collocating URET, TMA, and CPDLC.

**Participant Responsibilities:**

I am aware that to participate in this study I must be a certified professional controller who is qualified at an air traffic control facility and holds a current medical certificate. I will control traffic and answer any questions asked during the study to the best of my abilities. I will not discuss the content of the experiment with anyone until the study is completed.

**Participant's Assurances:**

I understand that my participation in this study is completely voluntary and I have the freedom to withdraw at any time without penalty. I also understand that the researchers in this study may terminate my participation if they feel this to be in my best interest. I understand that if new findings develop during the course of this research that may relate to my decision to continue participation, I will be informed.

I have not given up any of my legal rights or released any individual or institution from liability for negligence.

Dr. Sollenberger has adequately answered all the questions I have asked about this study, my participation, and the procedures involved. I understand that Dr. Sollenberger or another member of the research team will be available to answer any questions concerning procedures throughout this study.

If I have questions about this study or need to report any adverse effects from the research procedures, I will contact Dr. Sollenberger at (609) 485-7169.

**Compensation and Injury:**

I agree to immediately report any injury or suspected adverse effect to Dr. Randy Sollenberger at (609) 485-7169. Local clinics and hospitals will provide any treatment, if necessary. I agree to provide, if requested, copies of all insurance and medical records arising from any such care for injuries/medical problems.

**Signature Lines:**

I have read this informed consent form. I understand its contents, and I freely consent to participate in this study under the conditions described. I understand that, if I want to, I may have a copy of this form.

Research Participant:____________________________________________ Date:__________

Investigator:____________________________________________________ Date:__________

Witness:_______________________________________________________ Date:__________

APPENDIX B

Background Questionnaire

Instructions:

This questionnaire is designed to obtain information about your background and experience as an air traffic control specialist (ATCS). The information will be used to describe the participants in this study as a group. You will not be identified by name. Indicate your response by filling in the circle with a pen or pencil (or mark with an X ), writing on the blank line, or circling the percentage number where appropriate. Some rating scales have labels at either end and 10 numbered circles that represent different levels of response. Fill in one circle with a pen or pencil (or mark with an X) to indicate your level of response.

## Demographic Information and Experience

| | | |
|---|---|---|
| 1. What is your **gender**? | ○ Male | ○ Female |
| 2. Will you be **wearing corrective lenses** during this experiment? | ○ Yes | ○ No |
| 3. What is your **age**? | _____ years | _____ months |
| 4. How long have you worked as an **ATCS (include both FAA and military experience)**? | _____ years | _____ months |
| 5. How long have you worked as an **ATCS for the FAA**? | _____ years | _____ months |
| 6. How long have you been a **Certified Professional Controller** (or Full Performance Level Controller)? | _____ years | _____ months |
| 7. How long have you **actively controlled traffic** in the en route environment? | _____ years | _____ months |
| 8. How many of the **past 12 months** have you actively controlled traffic? | _____ months | |

## Sector Characteristics

| | | | |
|---|---|---|---|
| 9. Rate the **complexity** of the **sector** that you **work most frequently**. | Low Complexity | ①②③④⑤⑥⑦⑧⑨⑩ | High Complexity |

| | | |
|---|---|---|
| 10. Provide the approximate **dimensions** of your **most frequently worked sector**. | _____ nautical miles wide | _____ nautical miles long |

| | | |
|---|---|---|
| 11. Does your **most frequently worked sector** contain **special use** or **restricted airspace**? | ○ Yes | ○ No |

| 12. Describe the **traffic type** of your **most frequently worked sector** by assigning a **percentage** to the following categories: | |
|---|---|
| (A). Transitional Traffic to/from a Major Airport | 0 10 20 30 40 50 60 70 80 90 100 |
| (B). High Altitude En Route (FL240 and above) | 0 10 20 30 40 50 60 70 80 90 100 |
| (C). Low Altitude En Route (FL230 and below) | 0 10 20 30 40 50 60 70 80 90 100 |

| 13. Describe the **traffic mix** of your **most frequently worked sector** by assigning a **percentage** to the following categories (percentages must sum to 100%): | |
|---|---|
| (A). Air Carriers/Corporate Jets | 0 10 20 30 40 50 60 70 80 90 100 |
| (B). Air Taxi/Commuters | 0 10 20 30 40 50 60 70 80 90 100 |
| (C). Cargo | 0 10 20 30 40 50 60 70 80 90 100 |
| (D). General Aviation | 0 10 20 30 40 50 60 70 80 90 100 |
| (E). Military | 0 10 20 30 40 50 60 70 80 90 100 |
| (F). Other, specifiy ____________________ | 0 10 20 30 40 50 60 70 80 90 100 |
| Sum Total | 100% |

| | | | |
|---|---|---|---|
| 14. Rate how often you use **paper flight strips**. | Never | ①②③④⑤⑥⑦⑧⑨⑩ | Always |

## General Ratings

| | | | |
|---|---|---|---|
| 15. Rate your current **skill as an ATCS**. | Not Skilled | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely Skilled |

| | | | |
|---|---|---|---|
| 16. Rate your current **level of stress**. | Not Stressed | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely Stressed |

| | | | |
|---|---|---|---|
| 17. Rate your **level of motivation** to participate in this study. | Not Motivated | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely Motivated |

APPENDIX C

Generic Airspace

Guttman & Stein (1997) performed a study that compared ATCS performance in generic and home airspaces. The generic airspaces were designed to be comparable to the home airspaces on a number of factors, including number of airways, route length, sector size, traffic mix, and the number and altitudes of restricted areas. However, the generic airspace, as compared to the home sector, had a different direction of traffic flow, different sector boundaries and, different Letters-of-Agreement (LOAs). These differences were purposely introduced to induce learning on the part of the ATCS. In this study, the researchers designed traffic scenarios to realistically model the traffic of a moderately busy sector. They reported high correlations between a number of different ATC performance measurements taken in the simulations performed in the ATCSs home airspace and the simulations performed in the generic airspace. The performance measurements with high correlations between home and generic airspace included controller self-ratings, controller workload ratings, and system effectiveness variables (e.g. number and duration of push-to-talk communications, average transmission time, flight time, and distance flown). They also determined that the majority of controllers considered the simulations using generic airspace to be very realistic and that the generic sector itself was very representative of a typical sector. They concluded that airspace sectors used for simulations need to be easy to learn and have properties similar to that of real sectors. Earlier, Guttman, Stein, & Gromelski (1995) performed a similar study evaluating the use of a generic terminal radar approach control (TRACON) with comparable results.

Manning (2000) also evaluated the use of generic airspace in high-fidelity simulations. She found that a number of factors were important to consider when: a) designing traffic scenarios for real-time HITL simulations, b) training ATCSs on generic airspace, and c) training observers to make performance ratings during simulations. Manning stated, “The likelihood of accurately measuring ATCS performance increases with the extent to which one is able to place ATCSs in a standardized and realistic environment in which they must control traffic, and that affords reliable measurement of their performance.” First, Manning pointed out that scenarios should have moderately busy or busy traffic so ATCSs will be required to actively control traffic. Second, she felt that ATCSs should be trained to a certain level of proficiency on the airspace before testing begins. This training would ensure that all ATCSs are equally familiar with the generic airspace. In her study, ATCSs were required, after training, to take an airspace familiarization test and receive a score of 70% on both recall and recognition items before they were able to participate in the testing phase of the experiment. Finally, she concluded that simulation observers should receive extensive training with the rating scale to ensure a high level of inter-rater reliability.

At the US-European Action Plan 5 Practitioners Workshop hosted by the FAA WJHTC in 2002, researchers involved in conducting simulations formally discussed the advantages and disadvantages of using generic airspace. They also discussed how scenarios should be developed for use in experiments. A best practices paper from this workshop is currently in preparation that discusses the advantages and disadvantages of using generic airspace (see Table C-1). After evaluating the pros and cons of using generic airspace, we decided that because this study will examine systems which will be deployed across the NAS, a generic airspace would best allow us to generalize results to a variety of different airspaces (Willems, 2002).

Table C-1. Advantages and Disadvantages of Generic Airspace

| Advantages | Disadvantages |
|---|---|
| • Generic airspace is easy to learn<br>• Controllers start at a level playing field<br>• Using generic airspace enables researchers to create their own standard operating procedures<br>• A greater number of controllers are available to be recruited for experiments<br>• Results from experiments using generic airspace can be generalized to the NAS | • All participants must be trained on the generic airspace<br>• Researchers need to ensure that generic airspace has features that are consistent with actual airspace<br>• Developing generic airspace can be difficult and costly<br>• When using generic airspace, it may be difficult to generalize the results to a specific airspace |

By using generic airspace for the real-time HITL simulations, we will be able to capture real ATCS performance while controlling for individual differences related to an ATCS -- length of experience and home sector complexity (Guttman & Stein, 1997; Manning, 2000). As Manning points out, testing ATCSs in their home airspaces is not a viable option. This is due to inherent differences in traffic density and airspace layout that would not allow us to compare ATCS performance across different levels of difficulty. To the extent that ATCS performance in generic airspace is comparable to ATCS performance in real airspace, researchers can extrapolate results across different airspaces. This greatly reduces the costs of performing ATC studies while increasing realism by using real-time HITL simulations.

APPENDIX D

Post-Scenario Questionnaire

R-side Version

Instructions:

Please answer the following questions based upon your experience in the scenario just completed. The rating scales have labels at either end and 10 numbered circles that represent different levels of response. Fill in one circle with a pen or pencil (or mark with an X) to indicate your level of response OR mark ☐ N/A if the question deals with something you did not try at all during the simulation.

## Overall Performance, Workload, Situational Awareness, and Simulation Ratings

| | | | |
|---|---|---|---|
| 1. Rate your **overall level of ATC performance** during this scenario. | Extremely Poor | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely Good |
| 2. Rate your **workload due to communications with pilots** during this scenario. | Extremely Low | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely High |
| 3. How much **coordination with your D-side team member occurred** during this scenario? | None At All | ①②③④⑤⑥⑦⑧⑨⑩ | A Great Deal |
| 4. Rate your **workload due to coordination with your D-side team member** during this scenario. | Extremely Low | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely High |
| 5. Rate your **level of situational awareness** during this scenario. | Extremely Poor | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely Good |
| 6. Rate the **performance of the simulation pilots** in terms of their responding to control instructions and providing readbacks. | Extremely Poor | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely Good |
| 7. Rate the **difficulty** of this scenario. | Extremely Difficult | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely Easy |

## URET

| | | | |
|---|---|---|---|
| 8. Overall, how **easy was it to use URET** during this scenario? | Extremely Difficult | ①②③④⑤⑥⑦⑧⑨⑩ OR ☐ N/A | Extremely Easy |
| 9. How **easy was it to access information from the URET Aircraft List** when needed? | Extremely Difficult | ①②③④⑤⑥⑦⑧⑨⑩ OR ☐ N/A | Extremely Easy |
| 10. How **easy was it to access information from the URET Graphics Plan View Display** when needed? | Extremely Difficult | ①②③④⑤⑥⑦⑧⑨⑩ OR ☐ N/A | Extremely Easy |
| 11. How **easy was it to perform URET Trial Plans** when you wanted? | Extremely Difficult | ①②③④⑤⑥⑦⑧⑨⑩ OR ☐ N/A | Extremely Easy |
| 12. How often did you feel **URET caused clutter on the display**? | Never | ①②③④⑤⑥⑦⑧⑨⑩ OR ☐ N/A | Always |
| 13. What impact did **URET have on your workload**? | Negative (increased) | ①②③④⑤⑥⑦⑧⑨⑩ | Positive (decreased) |
| 14. How much **URET coordination with your D-side team member occurred**? | None At All | ①②③④⑤⑥⑦⑧⑨⑩ | A Great Deal |
| 15. What impact did **URET coordination with your D-side team member have on your workload**? | Negative (increased) | ①②③④⑤⑥⑦⑧⑨⑩ | Positive (decreased) |
| 16. What impact did **URET have on your situational awareness**? | Negative (decreased) | ①②③④⑤⑥⑦⑧⑨⑩ | Positive (increased) |
| 17. What impact did **URET have on your ability to control traffic safely**? | Negative (decreased) | ①②③④⑤⑥⑦⑧⑨⑩ | Positive (increased) |

18. Additional comments regarding URET:

______________________________________________________________

______________________________________________________________

______________________________________________________________

______________________________________________________________

## TMA

| | | | |
|---|---|---|---|
| 19. Overall, how **easy was it to use TMA** during this scenario? | Extremely Difficult | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely Easy |

| | | | |
|---|---|---|---|
| 20. How **easy was it to access information from the TMA List** when needed? | Extremely Difficult | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely Easy |

| | | | |
|---|---|---|---|
| 21. How often did you feel the **TMA List caused clutter on the display**? | Never | ①②③④⑤⑥⑦⑧⑨⑩ | Always |

| | | | |
|---|---|---|---|
| 22. What impact did **TMA have on your workload**? | Negative (increased) | ①②③④⑤⑥⑦⑧⑨⑩ | Positive (decreased) |

| | | | |
|---|---|---|---|
| 23. How much **TMA coordination with your D-side team member occurred**? | None At All | ①②③④⑤⑥⑦⑧⑨⑩ | A Great Deal |

| | | | |
|---|---|---|---|
| 24. What impact did **TMA coordination with your D-side team member have on your workload**? | Negative (increased) | ①②③④⑤⑥⑦⑧⑨⑩ | Positive (decreased) |

| | | | |
|---|---|---|---|
| 25. What impact did **TMA have on your situational awareness**? | Negative (decreased) | ①②③④⑤⑥⑦⑧⑨⑩ | Positive (increased) |

| | | | |
|---|---|---|---|
| 26. What impact did **TMA have on your ability to control traffic safely**? | Negative (decreased) | ①②③④⑤⑥⑦⑧⑨⑩ | Positive (increased) |

27. Additional comments regarding TMA:

## CPDLC

| | | | |
|---|---|---|---|
| 28. Overall, how **easy was it to use CPDLC** during this scenario? | Extremely Difficult | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely Easy |
| 29. How **easy was it to access information from the CPDLC Message Out View** when needed? | Extremely Difficult | ①②③④⑤⑥⑦⑧⑨⑩ OR ☐ N/A | Extremely Easy |
| 30. How **easy was it to access information from the CPDLC History Window** when needed? | Extremely Difficult | ①②③④⑤⑥⑦⑧⑨⑩ OR ☐ N/A | Extremely Easy |
| 31. How **easy was it to use the CPDLC Menu Text Window** when needed? | Extremely Difficult | ①②③④⑤⑥⑦⑧⑨⑩ OR ☐ N/A | Extremely Easy |
| 32. How **easy was it to access information from the Datablock CPDLC Status Line 0** when needed? | Extremely Difficult | ①②③④⑤⑥⑦⑧⑨⑩ OR ☐ N/A | Extremely Easy |
| 33. How **easy was it to use the Datablock CPDLC Fly-out Windows** when needed? | Extremely Difficult | ①②③④⑤⑥⑦⑧⑨⑩ OR ☐ N/A | Extremely Easy |
| 34. How **easy was it to use the CRD CPDLC Text Commands** when needed? | Extremely Difficult | ①②③④⑤⑥⑦⑧⑨⑩ OR ☐ N/A | Extremely Easy |
| 35. How often did you feel **CPDLC caused clutter on your display**? | Never | ①②③④⑤⑥⑦⑧⑨⑩ | Always |
| 36. What impact did **CPDLC have on your workload**? | Negative (increased) | ①②③④⑤⑥⑦⑧⑨⑩ | Positive (decreased) |
| 37. How much **CPDLC coordination with your D-side team member occurred**? | None At All | ①②③④⑤⑥⑦⑧⑨⑩ | A Great Deal |
| 38. What impact did **CPDLC coordination with your D-side team member have on your workload**? | Negative (increased) | ①②③④⑤⑥⑦⑧⑨⑩ | Positive (decreased) |

## CPDLC (continued)

| | | | |
|---|---|---|---|
| 39. What impact did **CPDLC have on your situational awareness**? | Negative (decreased) | ①②③④⑤⑥⑦⑧⑨⑩ | Positive (increased) |

| | | | |
|---|---|---|---|
| 40. What impact did **CPDLC have on your ability to control traffic safely**? | Negative (decreased) | ①②③④⑤⑥⑦⑧⑨⑩ | Positive (increased) |

| | | | |
|---|---|---|---|
| 41. What impact did **CPDLC Menu Text <u>crossing restrictions</u> have on your workload**? | Negative (increased) | ①②③④⑤⑥⑦⑧⑨⑩ OR ☐ N/A | Positive (decreased) |

| | | | |
|---|---|---|---|
| 42. What impact did **CPDLC Menu Text <u>crossing restrictions</u> have on your situational awareness**? | Negative (decreased) | ①②③④⑤⑥⑦⑧⑨⑩ OR ☐ N/A | Positive (increased) |

| | | | |
|---|---|---|---|
| 43. What impact did **CPDLC Menu Text <u>crossing restrictions</u> have on your ability to control traffic safely**? | Negative (decreased) | ①②③④⑤⑥⑦⑧⑨⑩ OR ☐ N/A | Positive (increased) |

44. Additional comments regarding CPDLC:

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Post-Scenario Questionnaire
D-side Version

Instructions:
Please answer the following questions based upon your experience in the scenario just completed. The rating scales have labels at either end and 10 numbered circles that represent different levels of response. Fill in one circle with a pen or pencil (or mark with an X) to indicate your level of response OR mark ☐ N/A if the question deals with something you did not try at all during the simulation.

## Overall Performance, Workload, Situational Awareness, and Simulation Ratings

| | | | |
|---|---|---|---|
| 1. Rate your **overall level of ATC performance** during this scenario. | Extremely Poor | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely Good |
| 2. Rate your **workload due to communications with pilots** during this scenario. | Extremely Low | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely High |
| 3. How much **coordination with your R-side team member occurred** during this scenario? | None At All | ①②③④⑤⑥⑦⑧⑨⑩ | A Great Deal |
| 4. Rate your **workload due to coordination with your R-side team member** during this scenario. | Extremely Low | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely High |
| 5. Rate your **level of situational awareness** during this scenario. | Extremely Poor | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely Good |
| 6. Rate the **performance of the simulation pilots** in terms of their responding to control instructions and providing readbacks. | Extremely Poor | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely Good |
| 7. Rate the **difficulty** of this scenario. | Extremely Difficult | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely Easy |

## URET

| | | | | |
|---|---|---|---|---|
| 8. Overall, how **easy was it to use URET** during this scenario? | Extremely Difficult | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely Easy |
| 9. How **easy was it to access information from the URET Aircraft List** when needed? | Extremely Difficult | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely Easy |
| 10. How **easy was it to access information from the URET Graphics Plan View Display** when needed? | Extremely Difficult | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely Easy |
| 11. How **easy was it to perform URET Trial Plans** when you wanted? | Extremely Difficult | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely Easy |
| 12. How often did you feel **URET caused clutter on the display**? | Never | ①②③④⑤⑥⑦⑧⑨⑩ | Always |
| 13. What impact did **URET have on your workload**? | Negative (increased) | ①②③④⑤⑥⑦⑧⑨⑩ | Positive (decreased) |
| 14. How much **URET coordination with your R-side team member occurred**? | None At All | ①②③④⑤⑥⑦⑧⑨⑩ | A Great Deal |
| 15. What impact did **URET coordination with your R-side team member have on your workload**? | Negative (increased) | ①②③④⑤⑥⑦⑧⑨⑩ | Positive (decreased) |
| 16. What impact did **URET have on your situational awareness**? | Negative (decreased) | ①②③④⑤⑥⑦⑧⑨⑩ | Positive (increased) |
| 17. What impact did **URET have on your ability to support your R-side team member**? | Negative (decreased) | ①②③④⑤⑥⑦⑧⑨⑩ | Positive (increased) |

18. Additional comments regarding URET:

______________________________________________

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## TMA

| | | | |
|---|---|---|---|
| 19. Overall, how **easy was it to use TMA** during this scenario? | Extremely Difficult | ①②③④⑤⑥⑦⑧⑨⑩ OR ☐ N/A | Extremely Easy |

| | | | |
|---|---|---|---|
| 20. How **easy was it to access information from the TMA List** when needed? | Extremely Difficult | ①②③④⑤⑥⑦⑧⑨⑩ OR ☐ N/A | Extremely Easy |

| | | | |
|---|---|---|---|
| 21. How often did you feel the **TMA List caused clutter on the display**? | Never | ①②③④⑤⑥⑦⑧⑨⑩ OR ☐ N/A | Always |

| | | | |
|---|---|---|---|
| 22. What impact did **TMA have on your workload**? | Negative (increased) | ①②③④⑤⑥⑦⑧⑨⑩ | Positive (decreased) |

| | | | |
|---|---|---|---|
| 23. How much **TMA coordination with your R-side team member occurred**? | None At All | ①②③④⑤⑥⑦⑧⑨⑩ | A Great Deal |

| | | | |
|---|---|---|---|
| 24. What impact did **TMA coordination with your R-side team member have on your workload**? | Negative (increased) | ①②③④⑤⑥⑦⑧⑨⑩ | Positive (decreased) |

| | | | |
|---|---|---|---|
| 25. What impact did **TMA have on your situational awareness**? | Negative (decreased) | ①②③④⑤⑥⑦⑧⑨⑩ | Positive (increased) |

| | | | |
|---|---|---|---|
| 26. What impact did **TMA have on your ability to support your R-side team member**? | Negative (decreased) | ①②③④⑤⑥⑦⑧⑨⑩ | Positive (increased) |

27. Additional comments regarding TMA:

______________________________________________________________

______________________________________________________________

______________________________________________________________

______________________________________________________________

## CPDLC

| | | | |
|---|---|---|---|
| 28. Overall, how **easy was it to use CPDLC** during this scenario? | Extremely Difficult | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely Easy |
| 29. How **easy was it to access information from the CPDLC Message Out View** when needed? | Extremely Difficult | ①②③④⑤⑥⑦⑧⑨⑩ OR ☐ N/A | Extremely Easy |
| 30. How **easy was it to access information from the CPDLC History Window** when needed? | Extremely Difficult | ①②③④⑤⑥⑦⑧⑨⑩ OR ☐ N/A | Extremely Easy |
| 31. How **easy was it to use the CPDLC Menu Text Window** when needed? | Extremely Difficult | ①②③④⑤⑥⑦⑧⑨⑩ OR ☐ N/A | Extremely Easy |
| 32. How **easy was it to access information from the Datablock CPDLC Status Line 0** when needed? | Extremely Difficult | ①②③④⑤⑥⑦⑧⑨⑩ OR ☐ N/A | Extremely Easy |
| 33. How **easy was it to use the Datablock CPDLC Fly-out Windows** when needed? | Extremely Difficult | ☒ N/A | Extremely Easy |
| 34. How **easy was it to use the CRD CPDLC Text Commands** when needed? | Extremely Difficult | ①②③④⑤⑥⑦⑧⑨⑩ OR ☐ N/A | Extremely Easy |
| 35. How often did you feel **CPDLC caused clutter on <u>your</u> display**? | Never | ①②③④⑤⑥⑦⑧⑨⑩ | Always |
| 36. What impact did **CPDLC have on your workload**? | Negative (increased) | ①②③④⑤⑥⑦⑧⑨⑩ | Positive (decreased) |
| 37. How much **CPDLC coordination with your R-side team member occurred**? | None At All | ①②③④⑤⑥⑦⑧⑨⑩ | A Great Deal |
| 38. What impact did **CPDLC coordination with your R-side team member have on your workload**? | Negative (increased) | ①②③④⑤⑥⑦⑧⑨⑩ | Positive (decreased) |

## CPDLC (continued)

| | | | |
|---|---|---|---|
| 39. What impact did **CPDLC have on your situational awareness**? | Negative (decreased) | ①②③④⑤⑥⑦⑧⑨⑩ | Positive (increased) |

| | | | |
|---|---|---|---|
| 40. What impact did **CPDLC have on your ability to support your R-side team member**? | Negative (decreased) | ①②③④⑤⑥⑦⑧⑨⑩ | Positive (increased) |

| | | | |
|---|---|---|---|
| 41. What impact did **CPDLC Menu Text <u>crossing restrictions</u> have on your workload**? | Negative (increased) | ①②③④⑤⑥⑦⑧⑨⑩ OR ☐ N/A | Positive (decreased) |

| | | | |
|---|---|---|---|
| 42. What impact did **CPDLC Menu Text <u>crossing restrictions</u> have on your situational awareness**? | Negative (decreased) | ①②③④⑤⑥⑦⑧⑨⑩ OR ☐ N/A | Positive (increased) |

| | | | |
|---|---|---|---|
| 43. What impact did **CPDLC Menu Text <u>crossing restrictions</u> have on your ability to control traffic safely**? | Negative (decreased) | ①②③④⑤⑥⑦⑧⑨⑩ OR ☐ N/A | Positive (increased) |

44. Additional comments regarding CPDLC:

______________________________________________

______________________________________________

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## NASA-TLX Ratings

### Definitions

**Mental Demand** – How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Were your tasks easy or demanding, simple or complex, exacting or forgiving?

**Physical Demand** – How much physical activity was required (e.g., data entry, strip marking, talking, pointing, etc.)? Were your tasks easy or demanding, slow or brisk, slack or strenuous, restful or laborious?

**Temporal Demand** – How much time pressure did you feel due to the rate or pace at which your tasks occurred? Was the pace slow and leisurely or rapid and frantic?

**Performance** – How successful do you think you were in accomplishing the goals of your tasks? How satisfied were you with your performance in accomplishing these goals?

**Effort** – How hard did you have to work (mentally and physically) to accomplish this level of performance?

**Frustration** – How insecure, discouraged, irritated, stressed, and annoyed versus secure, gratified, content, relaxed, and complacent did you feel in performing your tasks?

| | | | |
|---|---|---|---|
| 45. Rate your **mental demand** during this scenario. | Extremely Low | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely High |

| | | | |
|---|---|---|---|
| 46. Rate your **physical demand** during this scenario. | Extremely Low | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely High |

| | | | |
|---|---|---|---|
| 47. Rate your **temporal demand** during this scenario. | Extremely Low | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely High |

| | | | |
|---|---|---|---|
| 48. Rate your **performance** during this scenario. | Extremely Low | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely High |

| | | | |
|---|---|---|---|
| 49. Rate your **effort** during this scenario. | Extremely Low | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely High |

| | | | |
|---|---|---|---|
| 50. Rate your **frustration** during this scenario. | Extremely Low | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely High |

51. Do you have any comments or clarifications about these NASA-TLX questions?

____________________________________________________________

____________________________________________________________

APPENDIX E

Subject Matter Expert Observer Rating Form

Observer Code _________ Date _________

Controller _________ Scenario _________

INSTRUCTIONS

This form is designed to be used by supervisory air traffic control specialists to evaluate the effectiveness of controllers working in simulation environments. SATCSs will observe and rate the performance of controllers in several different performance dimensions using the scale below as a general purpose guide. Use the entire scale range as much as possible. You will see a wide range of controller performance. Take extensive notes on what you see. Do not depend on your memory. Write down your observations. Space is provided after each scale for comments. You may make preliminary ratings during the course of the scenario. However, wait until the scenario is finished before making your final ratings and remain flexible until the end when you have had an opportunity to see all the available behavior. At all times please focus on what you actually see and hear. This includes what the controller does and what you might reasonably infer from the actions of the pilots. Try to avoid inferring what you think may be happening. If you do not observe relevant behavior or the results of that behavior, then you may leave a specific rating blank. Also, please write down any comments that may help improve this evaluation form. Do not write your name on the form itself. You will not be identified by name. An observer code known only to yourself and the researchers conducting this study will be assigned to you. The observations you make do not need to be restricted to the performance areas covered in this form and may include other areas that you think are important.

ASSUMPTIONS

ATC is a complex activity that contains both observable and unobservable behavior. There are so many complex behaviors involved that no observational rating form can cover everything. A sample of the behaviors is the best that can be achieved, and a good form focuses on those behaviors that controllers themselves have identified as the most relevant in terms of their overall performance. Most controller performance is at or above the minimum standards regarding safety and efficiency. The goal of the rating system is to differentiate performance above this minimum. The lowest rating should be assigned for meeting minimum standards and also for anything below the minimum since this should be a rare event. It is important for the observer/rater to feel comfortable using the entire scale and to understand that all ratings should be based on behavior that is actually observed.

## Rating Scale Descriptors

***Remove this page and keep it available while doing ratings***

| SCALE | QUALITY | SUPPLEMENTARY |
|---|---|---|
| 1 | **Least Effective** | Unconfident, Indecisive, Inefficient, Disorganized, Behind the power curve, Rough, Leaves some tasks incomplete, Makes mistakes |
| 2 | **Poor** | May issue conflicting instructions, Doesn’t plan completely |
| 3 | **Fair** | Distracted between tasks |
| 4 | **Low Satisfactory** | Postpones routine actions |
| 5 | **High Satisfactory** | Knows the job fairly well |
| 6 | **Good** | Works steadily, Solves most problems |
| 7 | **Very Good** | Knows the job thoroughly, Plans well |
| 8 | **Most Effective** | Confident, Decisive, Efficient, Organized, Ahead of the power curve, Smooth, Completes all necessary tasks, Makes no mistakes |

| I - MAINTAINING SAFE AND EFFICIENT TRAFFIC FLOW |
| --- |
| II - MAINTAINING ATTENTION AND SITUATION AWARENESS |
| III - PRIORITIZING |
| IV - PROVIDING CONTROL INFORMATION |
| V - TECHNICAL KNOWLEDGE |
| VI - COMMUNICATING |

| |
|---|
| **1. What is the D-side doing? [Teamwork, Roles & Responsibilities]** |
| **2. What URET information is being exchanged between R-side & D-side team members?**<br>**How does the D-side use URET to support the R-side?**<br>**When does the D-side use URET Trial Plans?**<br>**Any differences in URET usage depending upon availability of other tools?** |
| **3. What TMA information is being exchanged between R-side & D-side team members?**<br>**How does the D-side use TMA to support the R-side?**<br>**When does the D-side interact with TMA?**<br>**Any differences in TMA usage depending upon availability of other tools?** |
| **4. What CPDLC information is being exchanged between R-side & D-side team members?**<br>**How does the D-side use CPDLC to support the R-side?**<br>**When does the R-side use CPDLC?**<br>**Any differences in CPDLC usage depending upon availability of other tools?** |

| **I - Maintaining Safe and Efficient Traffic Flow** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1. Maintaining Separation and Resolving Potential Conflicts ...........<br>• using control instructions that maintain appropriate aircraft and airspace separation<br>• detecting and resolving impending conflicts early<br>• recognizing the need for speed restrictions and wake turbulence separation | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** |
| 2. Sequencing Aircraft Efficiently ....................................................<br>• using efficient and orderly spacing techniques for arrival, departure, and en route aircraft<br>• maintaining safe arrival and departure intervals that minimize delays | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** |
| 3. Using Control Instructions Effectively/Efficiently .........................<br>• providing accurate navigational assistance to pilots<br>• issuing economical clearances that result in need for few additional instructions to handle aircraft completely<br>• ensuring clearances require minimum necessary flight path changes | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** |
| 4. Overall Safe and Efficient Traffic Flow Scale Rating ................... | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** |

| **II - Maintaining Attention and Situation Awareness** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 5. Maintaining Awareness of Aircraft Positions ................................<br>• avoiding fixation on one area of the radar scope when other areas need attention<br>• using scanning patterns that monitor all aircraft on the radar scope | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** |
| 6. Giving and Taking Handoffs in a Timely Manner.........................<br>• ensuring that handoffs are initiated in a timely manner<br>• ensuring that handoffs are accepted in a timely manner<br>• ensuring that handoffs are made according to procedures | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** |
| 7. Ensuring Positive Control ............................................................<br>• tailoring control actions to situation<br>• using effective procedures for handling heavy, emergency, and unusual traffic situations | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** |
| 8. Detecting Pilot Deviations from Control Instructions ...................<br>• ensuring that pilots follow assigned clearances correctly<br>• correcting pilot deviations in a timely manner | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** |
| 9. Correcting Own Errors in a Timely Manner..................................<br>• acting quickly to correct errors<br>• changing an issued clearance when necessary to expedite traffic flow | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** |
| 10. Overall Attention and Situation Awareness Scale Rating ............. | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** |

| III - PRIORITIZING | |
|---|---|
| 11. Taking Actions in an Appropriate Order of Importance................ <br>• resolving situations that need immediate attention before handling low priority tasks<br>• issuing control instructions in a prioritized, structured, and timely manner | **1 2 3 4 5 6 7 8** |
| 12. Preplanning Control Actions.......................................................... <br>• scanning adjacent sectors to plan for future and conflicting traffic<br>• studying pending flight strips in bay | **1 2 3 4 5 6 7 8** |
| 13. Handling Control Tasks for Several Aircraft................................. <br>• shifting control tasks between several aircraft when necessary<br>• communicating in timely fashion while sharing time with other actions | **1 2 3 4 5 6 7 8** |
| 14. Marking Flight Strips while Performing Other Tasks ................... <br>• marking flight strips accurately while talking or performing other tasks<br>• keeping flight strips current | **1 2 3 4 5 6 7 8** |
| 15. Overall Prioritizing Scale Rating ................................................... | **1 2 3 4 5 6 7 8** |

| IV - PROVIDING CONTROL INFORMATION | |
|---|---|
| 16. Providing Essential Air Traffic Control Information..................... <br>• providing mandatory services and advisories to pilots in a timely manner<br>• exchanging essential information | **1 2 3 4 5 6 7 8** |
| 17. Providing Additional Air Traffic Control Information.................. <br>• providing additional services when workload permits<br>• exchanging additional information | **1 2 3 4 5 6 7 8** |
| 18. Providing Coordination.................................................................. <br>• providing effective and timely coordination<br>• using proper point-out procedures | **1 2 3 4 5 6 7 8** |
| 19. Overall Providing Control Information Scale Rating .................... | **1 2 3 4 5 6 7 8** |

| V - Technical Knowledge | |
|---|---|
| 20. Showing Knowledge of LOAs and SOPs ......................................<br>• controlling traffic as depicted in current LOAs and SOPs<br>• performing handoff procedures correctly | **1 2 3 4 5 6 7 8** |
| 21a. Showing Knowledge of Aircraft Capabilities and Limitations.......<br>• using appropriate speed, vectoring, and/or altitude assignments to separate aircraft with varied flight capabilities<br>• issuing clearances that are within aircraft performance parameters | **1 2 3 4 5 6 7 8** |
| 21b. Showing Effective Use of Equipment.............................................<br>• updating data blocks<br>• using equipment capabilities | **1 2 3 4 5 6 7 8** |
| 22. Overall Technical Knowledge Scale Rating .................................. | **1 2 3 4 5 6 7 8** |

| VI - Communicating | |
|---|---|
| 23. Using Proper Phraseology..............................................................<br>• using words and phrases specified in the 7110.65<br>• using phraseology that is appropriate for the situation<br>• using minimum necessary verbiage | **1 2 3 4 5 6 7 8** |
| 24. Communicating Clearly and Efficiently ........................................<br>• speaking at the proper volume and rate for pilots to understand<br>• speaking fluently while scanning or performing other tasks<br>• ensuring clearance delivery is complete, correct and timely<br>• speaking with confident, authoritative tone of voice | **1 2 3 4 5 6 7 8** |
| 25. Listening to Pilot Readbacks and Requests ...................................<br>• correcting pilot readback errors<br>• acknowledging pilot or other controller requests promptly<br>• processing requests correctly in a timely manner | **1 2 3 4 5 6 7 8** |
| 26. Overall Communicating Scale Rating............................................. | **1 2 3 4 5 6 7 8** |

# APPENDIX F

## Exit Questionnaire

R-side Version

Instructions:

Please answer the following questions based upon your overall experience in the simulation. The rating scales have labels at either end and 10 numbered circles that represent different levels of response. Fill in one circle with a pen or pencil (or mark with an X) to indicate your level of response OR mark ☐ Unknown if the question deals with something you have no field experience with. Unless otherwise stated, the questions refer to your experience as an R-side controller with a D-side team member.

### Simulation Realism and Research Apparatus Ratings

| | | | |
|---|---|---|---|
| 1. Rate the **realism of the overall simulation experience** compared to actual ATC operations. | Extremely Unrealistic | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely Realistic |
| 2. Rate the **realism of the simulation URET implementation** compared to actual field operation. | Extremely Unrealistic | ①②③④⑤⑥⑦⑧⑨⑩ OR ☐ Unknown | Extremely Realistic |
| 3. Rate the **realism of the simulation TMA implementation** compared to actual field operation. | Extremely Unrealistic | ①②③④⑤⑥⑦⑧⑨⑩ OR ☐ Unknown | Extremely Realistic |
| 4. Rate the **realism of the simulation CPDLC emulation** compared to actual field operation. | Extremely Unrealistic | ①②③④⑤⑥⑦⑧⑨⑩ OR ☐ Unknown | Extremely Realistic |
| 5. Rate the **realism of the simulation DSR hardware** compared to actual DSR equipment. | Extremely Unrealistic | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely Realistic |
| 6. Rate the **realism of the simulation DSR software** compared to actual DSR functionality. | Extremely Unrealistic | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely Realistic |
| 7. Rate the **realism of the simulation generic airspace** compared to actual NAS airspace. | Extremely Unrealistic | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely Realistic |
| 8. Rate the **realism of the simulation traffic scenarios** compared to actual NAS traffic. | Extremely Unrealistic | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely Realistic |

| | | | |
|---|---|---|---|
| 9. To what extent did the **oculometer interfere** with your ATC performance? | None At All | ①②③④⑤⑥⑦⑧⑨⑩ OR ☐ N/A | A Great Deal |

| | | | |
|---|---|---|---|
| 10. To what extent did the **ATWIT online workload rating technique interfere** with your ATC performance? | None At All | ①②③④⑤⑥⑦⑧⑨⑩ | A Great Deal |

11. Do you have any comments or suggestions for improvement about our simulation capability?

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## URET

12. What URET information did you want from your D-side team member?

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13. When did you want URET Trial Plans data from your D-side team member?

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|---|---|---|
| 14. Did you **want different URET information** depending upon the availability of the other tools? | ○ Yes | ○ No |

If yes, please explain.

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15. Please explain the difference between how you controlled traffic with and without URET.

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## TMA

16. What TMA information (if any) did you want from your D-side team member?

17. When did you want assistance from your D-side team member with TMA?

| | | |
|---|---|---|
| 18. Did you **use TMA differently** depending upon the availability of the other tools? | ○ Yes | ○ No |

If yes, please explain.

19. Please explain the difference between how you controlled traffic with and without TMA.

## CPDLC

20. What CPDLC information (if any) did you want from your D-side team member?

21. When did you want your D-side team member to use CPDLC?

| 22. Did you **use CPDLC differently** depending upon the availability of the other tools? | ○ Yes | ○ No |
|---|---|---|

If yes, please explain.

23. Please explain the difference between how you controlled traffic with and without CPDLC.

# CPDLC (continued)

| 24. Were there any benefits in using **CPDLC Menu Text crossing restrictions**? | ○ Yes | ○ No |
|---|---|---|

If yes, please explain.

| 25. Were there any safety or other problems in using **CPDLC Menu Text crossing restrictions**? | ○ Yes | ○ No |
|---|---|---|

If yes, please explain.

26. What was your overall impression of the computer-human interface of the CPDLC D-side design (e.g., toolbar, window cycle, and default/preferred window location buttons)? Do you have any ideas for improvements?

## Tool Combinations

| 27. Did you notice any **problems with displays covering important information** in any of the tool combinations? | ○ Yes | ○ No |
|---|---|---|

If yes, please explain which tool combinations and what the problems were.

| 28. Did you notice any **inconsistent display characteristics** between any of the tools that could be confusing? | ○ Yes | ○ No |
|---|---|---|

If yes, please explain which tool combinations and what the problems were.

| 29. Did you notice any **inconsistency in the interaction** between any of the tools that could be confusing? | ○ Yes | ○ No |
|---|---|---|

If yes, please explain which tool combinations and what the problems were.

| 30. Did you notice **any other problems** in using any of the tool combinations? | ○ Yes | ○ No |
|---|---|---|

If yes, please explain which tool combinations and what the problems were.

| 31. Is there a need for **information transfer between any of the tools** that could benefit from automation? | ○ Yes | ○ No |
|---|---|---|

If yes, please explain.

| 32. Is there any **additional functionality** that you would like to have on any of the tools? | ○ Yes | ○ No |
|---|---|---|

If yes, please explain.

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| 33. Are there any **procedures that should be set up** due to the change in operations with the addition of the tools? | ○ Yes | ○ No |

If yes, please explain.

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| 34. As an <u>R-side Only controller</u>, did you have any **problems using the tools without D-side assistance**? | ○ Yes | ○ No |

If yes, please explain what the problems were.

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35. Is there anything else that we should have asked or that you would like to comment on?

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Exit Questionnaire

D-side Version

Instructions:

Please answer the following questions based upon your overall experience in the simulation. The rating scales have labels at either end and 10 numbered circles that represent different levels of response. Fill in one circle with a pen or pencil (or mark with an X) to indicate your level of response OR mark ☐ Unknown if the question deals with something you have no field experience with. Unless otherwise stated, the questions refer to your experience as a D-side controller assisting your R-side team member.

## Simulation Realism and Research Apparatus Ratings

| | | | |
|---|---|---|---|
| 1. Rate the **realism of the overall simulation experience** compared to actual ATC operations. | Extremely Unrealistic | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely Realistic |
| 2. Rate the **realism of the simulation URET implementation** compared to actual field operation. | Extremely Unrealistic | ①②③④⑤⑥⑦⑧⑨⑩ OR ☐ Unknown | Extremely Realistic |
| 3. Rate the **realism of the simulation TMA implementation** compared to actual field operation. | Extremely Unrealistic | ①②③④⑤⑥⑦⑧⑨⑩ OR ☐ Unknown | Extremely Realistic |
| 4. Rate the **realism of the simulation CPDLC emulation** compared to actual field operation. | Extremely Unrealistic | ①②③④⑤⑥⑦⑧⑨⑩ OR ☐ Unknown | Extremely Realistic |
| 5. Rate the **realism of the simulation DSR hardware** compared to actual DSR equipment. | Extremely Unrealistic | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely Realistic |
| 6. Rate the **realism of the simulation DSR software** compared to actual DSR functionality. | Extremely Unrealistic | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely Realistic |
| 7. Rate the **realism of the simulation generic airspace** compared to actual NAS airspace. | Extremely Unrealistic | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely Realistic |
| 8. Rate the **realism of the simulation traffic scenarios** compared to actual NAS traffic. | Extremely Unrealistic | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely Realistic |

| | | | |
|---|---|---|---|
| 9. To what extent did the **oculometer interfere** with your ATC performance? | None At All | ①②③④⑤⑥⑦⑧⑨⑩ OR ☐ N/A | A Great Deal |

| | | | |
|---|---|---|---|
| 10. To what extent did the **ATWIT online workload rating technique interfere** with your ATC performance? | None At All | ①②③④⑤⑥⑦⑧⑨⑩ | A Great Deal |

11. Do you have any comments or suggestions for improvement about our simulation capability?

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## URET

12. What URET information did you provide your R-side team member?

13. When did you use the URET Trial Plans feature?

| | | |
|---|---|---|
| 14. Did you **use URET differently** depending upon the availability of the other tools? | ○ Yes | ○ No |

If yes, please explain.

15. Please explain the difference between how you supported your R-side team member with and without URET.

## TMA

16. What TMA information (if any) did you provide your R-side team member?

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17. When did you assist your R-side team member with TMA?

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|---|---|---|
| 18. Did you **provide different TMA information** depending upon the availability of the other tools? | ○ Yes | ○ No |

If yes, please explain.

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19. Please explain the difference between how you supported your R-side team member with and without TMA.

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## CPDLC

20. What CPDLC information (if any) did you provide your R-side team member?

21. When did you use CPDLC?

| | | |
|---|---|---|
| 22. Did you **use CPDLC differently** depending upon the availability of the other tools? | ○ Yes | ○ No |

If yes, please explain.

23. Please explain the difference between how you supported your R-side team member with and without CPDLC.

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|---|---|---|
| 24. Were there any benefits in using **CPDLC Menu Text crossing restrictions**? | ○ Yes | ○ No |

If yes, please explain.

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|---|---|---|
| 25. Were there any safety or other problems in using **CPDLC Menu Text crossing restrictions**? | ○ Yes | ○ No |

If yes, please explain.

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26. What was your overall impression of the computer-human interface of the CPDLC D-side design (e.g., toolbar, window cycle, and default/preferred window location buttons)? Do you have any ideas for improvements?

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## Tool Combinations

| 27. Did you notice any **problems with displays covering important information** in any of the tool combinations? | ○ Yes | ○ No |
|---|---|---|

If yes, please explain which tool combinations and what the problems were.

| 28. Did you notice any **inconsistent display characteristics** between any of the tools that could be confusing? | ○ Yes | ○ No |
|---|---|---|

If yes, please explain which tool combinations and what the problems were.

| 29. Did you notice any **inconsistency in the interaction** between any of the tools that could be confusing? | ○ Yes | ○ No |
|---|---|---|

If yes, please explain which tool combinations and what the problems were.

| | | |
|---|---|---|
| 30. Did you notice **any other problems** in using any of the tool combinations? | ○ Yes | ○ No |

If yes, please explain which tool combinations and what the problems were.

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| 31. Is there a need for **information transfer between any of the tools** that could benefit from automation? | ○ Yes | ○ No |

If yes, please explain.

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| 32. Is there any **additional functionality** that you would like to have on any of the tools? | ○ Yes | ○ No |

If yes, please explain.

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| 33. Are there any **procedures that should be set up** due to the change in operations with the addition of the tools? | ○ Yes | ○ No |

If yes, please explain.

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|---|---|---|
| 34. As an R-side Only controller, did you have any **problems using the tools without D-side assistance**? | ○ Yes | ○ No |

If yes, please explain what the problems were.

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35. Is there anything else that we should have asked or that you would like to comment on?

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