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New Electronic Flight Data Interface Designs for Airport Traffic Control Towers: Initial Usability Test

Todd R. Truitt, Ph.D., Human Factors Team – Atlantic City, ATO-P
Robert Muldoon, Northrop Grumman Information Technology

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16. Abstract

The Federal Aviation Administration (FAA) is examining electronic alternatives to the paper flight progress strips that air traffic controllers currently use in Airport Traffic Control Towers (ATCTs). FAA researchers have recently developed new concepts and human-computer interface designs for the management of electronic flight data in ATCTs. The authors of this report use a part-task simulation to assess the usability of the new Electronic Flight Data Interface (EFDI) concepts. The authors present objective and subjective data to evaluate (a) the participants' ability to learn how to use each EFDI, (b) the participants' ability to use the EFDIs as designed with the touch sensitive display, and (c) whether the participants' performance changes over a short period of time.

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Dino Piccione (FAA) – sponsor, program manger – advanced air traffic systems
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Dallas Shiles (Barco) – software development
Valentina Velez (L3/Titan) – software development
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Ed Little (L3/Titan) – network administrator
Albert Macias (FAA) – laboratory infrastructure management
Otto Smith (L3/Titan) – laboratory infrastructure management
John Dilks (L3/Titan) – laboratory infrastructure development
Wallace Daczkowski (L3/Titan) – laboratory infrastructure development
April Jackman (Northrop Grumman IT) – technical editor
Jean Dunn (Northrop Grumman IT) – technical editor
Dan Warburton (FAA) – software development
The Entire Target Generation Facility Team – software development

Executive Summary

Researchers from the Human Factors Team – Atlantic City have developed two prototype Electronic Flight Data Interfaces (EFDIs) for handling electronic flight data in Airport Traffic Control Towers (ATCTs). The Integrated EFDI combines flight data with a surface surveillance system. The Perceptual-Spatial (P-S) EFDI uses the same design principles as the Integrated EFDI but does not rely on surface surveillance. In addition, the P-S EFDI may serve as a backup to the Integrated EFDI in case surface surveillance becomes inoperable. The Federal Aviation Administration is interested in these new concepts because they potentially provide a new means for ATCT controllers to manage flight data and share information with other facilities. The EFDIs provide new tools and processes that should improve efficiency and safety. However, because the EFDIs change the way that controllers manage and interact with flight data, we must conduct usability testing to ensure that the EFDIs are effective, easy to learn, and easy to use.

The current report describes the method and results from an initial usability test of the EFDIs. The participants included current and supervisory ATCT controllers, who worked in teams of two (one local controller and one ground controller) to manage flight data with the EFDIs in a part-task simulation. The participants completed a training protocol and practice scenarios before engaging the test scenarios. Throughout the simulation, the researchers observed the participants' behavior and recorded audio/video data and EFDI interaction data. We used these data to calculate error rates and to assess whether the participants' performance changed after practice. The researchers also collected subjective responses from the participants regarding the usability of the EFDIs.

The results show that the participants were able to learn how to operate the EFDIs rather quickly. However, they may not have had enough time to learn how to use the touch sensitive displays reliably. For the Integrated EFDI, the participants had an error rate of 16% during the practice and 12% during the test. For the P-S EFDI, the participants had an error rate of 7% during the practice and 8% during the test. The relatively high error rates resulted from a few EFDI actions that the participants had difficulty performing. Overall, the participants' responses to the EFDIs were favorable. The participants thought the EFDIs were well organized and easy to use. They thought that the EFDIs required little effort, provided all of the necessary flight data, and supported their awareness of the airport traffic situation. However, there were several functions that were difficult to use, and this may have contributed to the participants' concerns that the EFDIs may cause too much "head down" time and may be labor intensive in some situations. We make recommendations to improve the usability of the EFDIs by suggesting changes for difficult-to-perform actions and by considering the participants' suggestions for new features.

1. INTRODUCTION

Researchers of the Federal Aviation Administration (FAA) Human Factors Team – Atlantic City designed two prototype Electronic Flight Data Interfaces (EFDIs) for use in Airport Traffic Control Towers (ATCTs) (see Truitt, 2006a). The goals of the EFDI designs are to improve the display, use, communication, coordination, transfer, and tracking of flight data in ATCTs. The new designs aim to improve efficiency and safety by consolidating information into a single display, by providing new tools to help controllers manage physical and cognitive workload, and by presenting information to support the controllers' awareness of the traffic situation. However, the EFDIs change the ATCT controllers' tasks in several ways; well-learned information formats are changed, many tasks such as marking Flight Progress Strips (FPSs) are automated, and new forms of user input are required. The present study examines the usability of the EFDIs. In particular, we examine how well controllers are able to learn and use the EFDIs' human-computer interfaces.

1.1 Background

We formed a working group of controllers, human factors experts, and software developers to identify and examine the most common tasks that ATCT controllers perform. We then created new concepts for electronic flight data handling that were unconstrained by historical designs (i.e., FPSs). We used an interface design process based on The Bridge methodology (Dayton, McFarland, & Kramer, 1998) to design the EFDIs. In conjunction with continuous usability testing throughout the development process, concepts from The Bridge allowed the interface design team to address numerous usability problems before the software development began. Before building functional prototypes, we examined task flows and created paper prototypes that we subjected to repeated usability testing. By using low-cost prototypes, we were able to ensure that the high-cost functional interfaces would perform as expected. The paper models, in conjunction with numerous drawings of the interface, helped the software developers transform the designs into functional interfaces. Truitt (2006a) provides a full description of the design and development process.

We designed and developed two different EFDIs based on the results of the working group and a previous literature review (Truitt, 2006b). We based the EFDI designs on the same set of principles and information requirements, but each EFDI supports flight data management at ATCTs with different types of infrastructure. The Integrated EFDI (see Figure 1) consolidates electronic flight data with a surface surveillance system. We chose to use the Airport Surface Detection Equipment – Model X (ASDE-X) as the surface surveillance system because it is an operational system and because we already had prototype software available that we could use as a starting point for software development. However, any surface surveillance system would suffice. The Integrated EFDI displays lists of Flight Data Elements (FDEs) and a readout area on either the left or right side. The FDEs only display the information that controllers need for either local or ground operations. Aircraft position symbols and data blocks appear in a situation display next to the FDEs (see Figure 2). If the surface surveillance system does not automatically associate an aircraft's flight data with its position symbol, then the controller must perform this action manually.

Figure 1. The primary elements of the ground controller's Integrated EFDI including the airport situation display, electronic flight data lists, and readout area.

Figure 2. FDEs and data blocks on the Integrated EFDI.

The Perceptual-Spatial (P-S) EFDI (see Figure 3) does not use a surface surveillance system. Rather, the P-S EFDI provides electronic flight data capabilities along with a surface map of the airport that controllers use to spatially organize information (see Figure 4). The P-S EFDI

supports the controllers' memory for aircraft position through movement of the FDEs (see Figure 4). The P-S EFDI also serves as a backup system to the Integrated EFDI in case surface surveillance becomes inoperative.

Figure 3. The primary elements of the P-S EFDI including flight data elements, readout area, buttons, and system information window.

Figure 4. FDEs for outbound aircraft on the P-S EFDI.

Both EFDIs accommodate the local and ground controller positions with touch sensitive displays that communicate with one another, so that controllers can easily share information. Actions that take place on one controller position are reflected on other relevant positions. The EFDIs automate most FPS markings, integrate information into a single display, and provide new tools such as timing information for controllers. Both EFDIs present only a subset of the entire set of flight data for each aircraft depending on an aircraft's current state (e.g., pending, arrival, departure, inbound, outbound) while still allowing access to the complete set of flight data upon request. The EFDIs also incorporate new tools for controllers to help them organize the flight data, reduce their physical and mental workload, alert them to potentially dangerous situations, and communicate and coordinate information between the local and ground controller positions. See Truitt (2006a) for complete details on the design process and functionality of each EFDI.

Once the prototype EFDIs were fully functional, we conducted usability testing to identify any remaining problems and to ensure that actual users could learn to use and operate the EFDIs in an efficient and effective manner. We wanted to make sure that the EFDIs were usable and easy to learn.

Nielsen and Mack (1994) presented a number of usability inspection methods that researchers may employ in an evaluation. These inspection methods include heuristic evaluation, guideline reviews, pluralistic walkthroughs, consistency inspections, standards inspections, cognitive walkthroughs, formal usability inspections, and feature inspections. Nielsen and Mack also identified four general approaches to evaluate user interfaces: automatic, empirical, formal, and informal. Automatic approaches use evaluation software to assess interface usability. Empirical methods involve real users and elicit feedback from them. Formal methods use models such as Goals, Operators, Methods, and Selection Rules (Card, Moran, & Newell, 1983) to calculate a measure. Informal methods use rules of thumb, general skill, knowledge, and evaluator experience. However, Nielsen and Mack found that "automatic methods do not work and formal methods are very difficult to apply and do not scale up well to complex, highly interactive user interfaces" (p. 2). One informal method of interface evaluation, the heuristic evaluation, employs usability specialists to assess the graphical user interface with respect to established principles of usability, or heuristics. The heuristics address concepts of usability including visibility of system status, correspondence between the system and the real world, user control and freedom, consistency and standards, error prevention, flexibility and efficiency of use, and aesthetic and minimalist design. However, the limitation of heuristic evaluation is that it only identifies potential problems. According to Lauesen (2005), heuristic evaluation only finds about 50% of the problems and also identifies about 50% false problems. Because of the limitations of heuristic evaluation, automatic, and formal methods, we decided to use a high fidelity part-task simulation as the foundation for an informal, empirical evaluation of the EFDIs.

1.2 Scope

The scope of the current study is limited to the particular EFDI prototype designs and functionality, airport layout, and scenarios used in the test. Because we were not able to simulate pilot interactions, the results of this study are limited to an airport-traffic monitoring task.

1.3 Purpose

The purpose of this research is to test the usability of the Integrated and the P-S EFDIs. We want to evaluate (a) the participants' ability to learn how to use each EFDI, (b) whether participants are able to use the EFDIs as designed with the touch sensitive display, and (c) how the participants' performance changes over time. We will apply the results from these initial usability tests to make design changes that improve the EFDIs and inform the methodology of future tests.

2. METHOD

We conducted the usability test at the FAA's Research, Development, & Human Factors Laboratory (RDHFL) during May 2-5, 2006.

2.1 Participants

Four ATCT experts served as participants. The participants were all supervisors from different facilities including Evansville Regional ATCT, Traverse City ATCT, Milwaukee Mitchell (MKE) ATCT, and FAA Quality Assurance. All 4 of the participants were male; 3 of them wore corrective lenses during the experiment. Only 2 of the participants had controlled traffic in an ATCT during the previous 12 months, but all 4 participants were highly experienced controllers. The participants rated their stress as low and their skill as a Certified Professional Controller as high. All of the participants indicated a high level of motivation to participate in the study. Table 1 shows the means and standard deviations (*SD*s) of the participants' responses to the Biographical Questionnaire (see Appendix A).

Table 1. Responses for the Biographical Questionnaire

Item	**Mean (*SD*)**
What is your age (years)?	49.25 (4.65)
How long (years) have you worked as a Certified Professional Controller (Military & FAA)?	17.17 (9.21)
How long (years) have you worked as a CPC for the FAA?	12.33 (6.39)
How long (years) have you actively controlled traffic in an Airport Traffic Control Tower?	18.19 (5.70)
How many of the past 12 months have you actively controlled traffic in an Airport Traffic Control Tower?	6.00 (6.93)
Rate your current skill as a CPC.	7.75 (0.96)
Rate your current level of stress.	1.75 (0.96)
Rate your level of motivation to participate in this study.	9.50 (0.58)

The participants were familiar with at least the basic functions of ASDE-X map control, such as viewing range changes and map rotation. The participant from MKE was a highly experienced user of ASDE-X.

2.2 Personnel

A primary investigator and a research assistant conducted the usability test. The primary investigator served as the main experimenter and provided instructions to the participants, directed the training protocol, answered questions, ensured proper data collection, and directed interviews. Both researchers observed and recorded usability problems throughout the study.

2.3 Equipment and Materials

We selected the hardware and designed the software used in this study to suit the needs of our concept research. Software developers from the RDHFL Future Laboratories Group and the Target Generation Facility (TGF) created all of the software necessary to run the part-task simulation.

2.3.1 Hardware

The local and ground controller workstations each included a computer and a VarTech Systems, Inc. touch sensitive display. The 21.3″ display has an active area of 17″ (432 mm) wide and 12.75″ (324 mm) high with a 1600 x 1200-pixel format and a viewing angle of 85°. We selected the high-resolution display as the hardware platform for the EFDIs to increase our capacity to present information. The display uses resistive technology to enable a touch sensitive surface that participants could activate with their fingertips. We mounted each 30.4 lb (13.82 kg) display on a custom-built stand that allowed the participants to adjust the horizontal and vertical viewing angles. Each workstation also included an ASDE-X keyboard and trackball/keypad manufactured by Cortron, Inc. as additional input devices. Figure 5 shows the basic hardware configuration of an EFDI controller workstation. We conducted the usability study with a total of three controller workstations. We also used a single 28″ 2048 x 2048-pixel Barco display as a Tower Display Workstation (TDW) to present simulated, short-range airborne radar information to the participants.

Figure 5. An EFDI controller workstation including touch sensitive display, display mount, ASDE-X keyboard, and trackball/keypad.

2.3.2 Software

We used the Distributed Environment for Simulation, Rapid Engineering, and Experimentation (DESIREE) software along with the TGF to generate and display the simulated traffic scenarios. The TGF uses realistic aircraft models and associated flight plans to generate the simulated aircraft tracks. The flight plans, created by Subject Matter Experts (SMEs), store the relevant information for each aircraft in an airport traffic scenario. The DESIREE software presented the aircraft tracks, generated the EFDI, and recorded user interactions for subsequent analysis.

2.3.3 Traffic Scenarios

Two SMEs created traffic scenarios for Boston/Logan International Airport (see Appendix B) using a 27/33 runway configuration. The 27/33 runway configuration provides several prototypical characteristics that are of general interest in developing new interfaces for flight data management. For example, both simple and complex taxi routes are available, and there are crossing and parallel runways.

The usability test employed one 30-min base traffic scenario for training and practice and one 30-min base traffic scenario for testing. The training and practice scenarios began without any aircraft occupying the airport surface. The testing scenario began with aircraft occupying the airport as if the participant had assumed responsibility of the position from another controller. We created different versions of the scenarios by modifying all of the aircraft call signs in the base scenarios. In effect, all of the participants experienced the exact same scenario during each of the respective training, practice, and testing sessions. Using different versions of the same scenarios reduces the extraneous effects of task load and traffic patterns while preventing the participants from recognizing the traffic scenarios. The SMEs designed the scenarios with an arrival/departure rate estimated at 40 aircraft per hour based on the findings of Simmons, Boan, and Massimini (2000). The scenarios generated an arrival and a departure aircraft about every 1.5 min. The base scenarios distributed aircraft among the primary crossing runways, 27 and 33L, and the secondary parallel runway, 33R.

2.4 Procedure

The participants worked in two groups of two. Before data collection began, each participant read and signed an Informed Consent Statement (see Appendix C). Each participant then completed the Biographical Questionnaire (see Appendix A). Next, the experimenter presented the participants with the overall objective and scope of the study and a general schedule of events. The participants also received information about the types of data that the experimenters would collect during the study.

Before learning to use the EFDIs, the experimenter provided some basic training on use of the touch sensitive display. The experimenter showed the participants how to adjust the horizontal and vertical viewing angles of the display. He also recommended a direct viewing angle with the display because an oblique viewing angle causes errors due to parallax, especially when first learning to use the EFDIs.

We counterbalanced the order of the EFDI presentation. The first group of participants received training on the Integrated EFDI first, followed by two sessions of data collection for that EFDI. The first group then received training on the P-S EFDI followed by two more sessions of data

collection. The second group completed training and data collection on the P-S EFDI first, followed by the Integrated EFDI. The experimenter used a structured, hands-on training protocol to provide a general overview and to describe how to manage flight data with each EFDI (see Appendix D). For each EFDI task, the experimenter described how to perform the task and the participants took the appropriate actions on the EFDI. Training continued until the participants were able to successfully perform each task. After learning to operate one of the EFDIs, the participants performed each task for that EFDI once again to reinforce their learning and to demonstrate their level of understanding. If a participant did not understand a task or was unable to successfully complete a task during training, the experimenter demonstrated the task and then asked the participant to attempt the task again to verify that he could perform it successfully. Training continued until both participants in the group were able to perform all of the EFDI tasks for both the ground and local controller positions.

Once the participants completed training on an EFDI, the experimenter randomly assigned one of the participants in the group to the local controller position and the other to the ground controller position. The participants then prepared their displays by adjusting the location of the movable buttons, maps, and the viewing angle of the touch screen. The research assistant then started the audio/video recording, and the experimenter provided instructions to the participants. We placed an omnidirectional microphone on the table between the local and ground controller positions to record ambient noise and conversation. Cameras mounted on the ceiling of the experiment room recorded an over-the-shoulder view of the local and ground controller EFDIs. The experimenter instructed the participants that they would be monitoring a previously recorded airport traffic scenario and that they were to maintain all flight data. The participants were free to talk to each other to communicate or coordinate information as needed. Once the participants received and understood the instructions, the experimenter started the simulated traffic scenario and data collection began.

The participants did not have an out-the-window (OTW) view or voice communications with pilots, but they did have access to aircraft position information provided by the ASDE-X and TDW displays. An ASDE-X display was located between the local and ground controller positions to provide surface surveillance when the participants were using the P-S EFDI. The TDW was located behind the participants and presented aircraft location, callsign, and aircraft type. The participants could adjust the TDW display range at any time.

At 5-min intervals during the scenario, the experimenter instructed the participants to perform predefined tasks as workload permitted (see Appendix E). This was necessary to ensure that the participants performed all of the possible actions at least once. At the end of the first data collection scenario for an EFDI, the participants switched controller positions and completed the second data collection scenario. The participants completed the Post-Scenario Questionnaire (PSQ) after each data collection scenario (see Appendix F). The participants also completed the appropriate EFDI general questionnaire after completing both data collection scenarios and the PSQs for an EFDI (see Appendix G for the Integrated EFDI General Questionnaire and Appendix H for the P-S EFDI General Questionnaire). The next day, we repeated the entire training and data collection procedure for the second EFDI.

3. RESULTS

We tested the usability of the EFDIs by collecting objective and subjective measures. The goal of our data collection was to understand how the participants used the EFDIs, to see whether they improved after practice, and to identify tasks that were difficult to perform. Because the Integrated EFDI and P-S EFDI are separate solutions for different ATCT environments, we will not compare the results for each EFDI to one another. We report only descriptive statistics due to the small sample population.

The following sections present the results for the ground and local controller positions, including the overall results for real-time user data, questionnaires, observational data, and interview data. The results compare real-time interaction data from practice and test scenarios to identify changes in performance over time. We pay special attention to tasks that were particularly difficult to perform and propose remedies. Finally, we identify features as candidates for implementation in the next version of the EFDIs.

3.1 Integrated EFDI

The Integrated EFDI provides controllers with actual aircraft positions and associates each aircraft with its flight data. The Integrated EFDI should provide a number of benefits to controllers in that it integrates information onto a single display and reduces the need to shift visual attention from one source of information to another. By combining relevant flight data information on an electronic touch sensitive display, we may be able to reduce controller task load while providing new tools that improve airport safety and efficiency. However, the interface must be effective, easy to use, and accepted by controllers.

3.1.1 Interaction Data

We gathered interaction data during the practice and test scenarios to better understand the participants' actions. The interaction data describes what actions the participants performed and records a time stamp for each successful action. The audio/video recordings enabled us to identify missed actions and errors. To calculate an error rate percentage for each EFDI action, we divided the mean number of misses (M) by the sum of M and the mean number of successes (S) and then multiplied the result by 100. We focus on the combined data from the local and ground controller positions because the EFDI actions were primarily the same on both positions and because of our relatively small sample size (Appendix I shows the interaction data for each controller position).

The participants were able to learn how to operate the Integrated EFDI within the time allotted for training and practice. They were able to complete all of the required EFDI actions during the test scenarios. Table 2 shows the overall practice and test interaction data. The overall error rate for the Integrated EFDI was 16% during the practice and 12% during the test.

Although there was a great deal of variability between the participants, they performed data block selections more often than any other action. This is an interesting finding because the participants could select flight data by either selecting a data block or an FDE. Rather than searching through

the list of FDEs to find flight data, the participants preferred to select the data block located on the airport surface map. The fact that they chose to select a data block more often than an FDE suggests that there is an advantage to correlating flight data with aircraft position for the visual search task. Selecting a data block also produced a lower error rate (5% vs. 9%).

Table 2. Overall Interaction Data for the Integrated EFDI

	Practice			Test		
EFDI Action	**Mean (*SD*) Number of Actions**	**Mean (*SD*) Number of Misses**	**Error Rate (%)**	**Mean (*SD*) Number of Actions**	**Mean (*SD*) Number of Misses**	**Error Rate (%)**
Data Block Select	59.75 (42.45)	4.00 (4.08)	6	84.75 (55.29)	4.75 (3.06)	5
FDE Select	39.25 (25.26)	3.50 (4.43)	8	58.50 (25.01)	6.13 (6.45)	9
FDE Resequence	3.25 (2.63)	0.25 (0.50)	7	9.00 (10.14)	1.13 (1.64)	11
Reposition Data Block	19.50 (13.92)	1.25 (0.96)	6	41.50 (30.46)	5.00 (4.75)	11
List Transfer	21.00 (0.00)	0.50 (0.71)	2	24.75 (0.96)	1.50 (1.00)	6
Position Transfer	35.25 (1.50)	5.75 (3.50)	14	43.00 (2.45)	4.75 (2.49)	10
Assign Alt. & Hdg.	0.75 (0.50)	0.00 (0.00)	0	0.25 (0.46)	0.00 (0.00)	0
Assign Altitude	0.50 (0.58)	0.00 (0.00)	0	0.50 (0.53)	0.00 (0.00)	0
Assign Heading	1.75 (2.36)	0.00 (0.00)	0	2.50 (5.50)	0.13 (0.35)	5
Ack. Assignment	3.75 (3.20)	0.25 (0.50)	6	3.13 (5.25)	0.13 (0.35)	4
Ack. Expired Generic Timer	1.50 (0.58)	3.50 (1.00)	70	1.13 (0.35)	0.88 (1.13)	44
Ack. Expired Aircraft Timer	3.25 (1.26)	7.75 (9.22)	71	2.13 (1.25)	2.13 (3.27)	50
Ack. ATIS Update Indicator	17.25 (10.97)	12.75 (14.59)	43	26.63 (6.02)	13.00 (7.03)	33
Ack. Common ATIS Update	2.00 (0.00)	0.25 (0.50)	11	2.00 (0.00)	0.63 (0.92)	24
Assign Runway	1.75 (1.71)	0.50 (0.58)	22	1.38 (1.19)	0.38 (0.52)	21
Assign Intersection	1.75 (2.87)	0.50 (0.58)	22	1.88 (1.96)	0.50 (0.76)	21
Deselect Error	1.25 (1.50)	–	–	1.88 (1.36)	–	–

Note. Dashes indicate that quantitative data was not collected for that item.

Although selecting a data block was the participants' preferred method of selecting flight data, a data block selection may lead to a deselect error. We counted a deselect error when a participant tried to perform an action without having first selected the associated flight data. There was a potential for a deselect error to occur because we designed the EFDI to use a select- action-deselect method of input. In other words, the user must first select the flight data to act upon and then select the action to take. Upon completing an action, the affected flight data are automatically deselected. We chose this sequence of actions to reduce input error and to provide

feedback to the user that an action had taken place. However, because the Integrated EFDI allows the user to select flight data via the data blocks or FDEs for reasons other than to take an action (e.g., looking at flight plan readout or moving a data block), the user may inadvertently deselect an already-selected object when trying to take an action. On average, the participants committed less then two deselect errors during the 30-min scenarios.

The participants frequently completed list transfers and position transfers by selecting an FDE or data block and then selecting the appropriate header (ground, departure, etc.). The participants had an error rate of 6% for list transfers and 10% for position transfers. The participants also acknowledged the Automatic Terminal Information Service (ATIS) update indicator quite frequently, but they had a relatively high error rate (33%) when doing so. The touch sensitive area of the ATIS update indicator was too small and difficult to activate.

The participants performed 10 of the 16 actions only three times or less on average in the test condition. These infrequently performed actions also had some of the highest error rates. The participants had the highest error rate when acknowledging an expired generic timer and an expired aircraft timer (44% and 50%, respectively). Expired timers did not occur very frequently, but one-half of the participants' attempts to acknowledge an expired timer resulted in a missed action. The aircraft timer icon is much smaller than the generic timer icon, but the error rate was high for both. Assigning runway and intersection assignments also occurred infrequently but had high error rates (21%). FDE resequencing caused the participants some trouble with an error rate of 11%. We discovered during the usability test that one of the stationary FDEs may obscure all or part of the moving FDE frame during FDE resequencing. Obscuring the FDE frame made it difficult to visually track an FDE while dragging it to another location within a list.

3.1.2 Post-Scenario Questionnaire

The participants completed the PSQ after each test scenario. The interface remained visible while the participants completed the PSQ, so they could refer to it as needed. Responses on the PSQ ranged from 1 (*Extremely Low*) to 10 (*Extremely High*). The pattern of responses for the ground and local controller positions were similar. Overall, the participants rated the Integrated EFDI as requiring low levels of effort while still providing adequate information to maintain awareness (see Table 3). The participants' ratings indicate that they thought that the Integrated EFDI required very low effort to use the touch sensitive display and to maintain the flight data. They indicated that they were able to find all of the necessary flight information. The ratings also suggest that the participants had a high level of awareness of the overall traffic situation, including current and projected aircraft positions and potential runway incursions. However, the participants rated the salience of the expired timers as low. They also rated the salience of updated ATIS information as moderate. Appendix J shows the participants' comments for each PSQ item.

Table 3. Post-Scenario Questionnaire Data for the Integrated EFDI

PSQ Item	Ground Mean (*SD*)	Local Mean (*SD*)	Overall Mean (*SD*)
Rate the effort needed to select FDEs.	2.25 (1.89)	2.25 (1.89)	2.25 (1.75)
Rate the effort needed to select data blocks.	1.75 (0.96)	1.25 (0.50)	1.50 (0.76)
Rate the effort needed to resequence FDEs.	3.00 (1.41)	3.50 (1.73)	3.25 (1.49)
Rate the effort needed to maintain data block separation.	2.50 (1.29)	3.75 (2.36)	3.13 (1.89)
Rate your ability to detect an ATIS update.	5.50 (3.00)	5.75 (2.63)	5.63 (2.62)
Rate the salience of the FDE ATIS indicator.	6.50 (2.38)	5.50 (3.51)	6.00 (2.83)
Rate the effort needed to set the generic timer.	2.25 (0.96)	2.25 (1.89)	2.25 (1.39)
Rate the salience of an expired generic timer.	4.00 (1.83)	3.75 (2.87)	3.88 (2.23)
Rate the effort needed to set an aircraft specific timer.	2.50 (1.29)	2.50 (1.91)	2.50 (1.51)
Rate the salience of an expired aircraft specific timer.	3.75 (2.22)	4.50 (1.91)	4.13 (1.96)
Rate the adequacy of feedback for completed actions.	6.50 (3.11)	6.50 (2.38)	6.50 (2.56)
Rate the overall effort needed to use the touch screen.	2.25 (1.26)	3.00 (2.16)	2.63 (1.69)
Rate the effort needed to amend flight data.	1.75 (0.50)	2.00 (0.82)	1.88 (0.64)
Rate the salience of amended flight data.	8.00 (0.00)	6.00 (3.37)	7.00 (2.45)
Rate the effort needed to highlight flight data.	1.50 (0.58)	2.00 (1.41)	1.75 (1.04)
Rate the salience of highlighted flight data.	7.75 (1.89)	6.50 (3.70)	7.13 (2.80)
Rate the overall effort needed to maintain flight data.	2.00 (0.82)	2.00 (0.82)	2.00 (0.76)
Rate the salience of expected departure clearance time information.	8.25 (1.26)	6.00 (3.56)	7.13 (2.75)
Rate your ability to find necessary flight information.	8.50 (1.29)	7.25 (3.50)	7.88 (2.97)
Rate your ability to detect aircraft on the runway due to a TIPH clearance.	8.00 (1.83)	6.75 (4.03)	7.38 (2.97)
Rate your awareness for current aircraft locations.	8.25 (1.71)	7.50 (2.65)	7.88 (2.10)
Rate your awareness for projected aircraft locations.	7.50 (3.11)	7.00 (2.83)	7.25 (2.76)
Rate your awareness for potential runway incursions.	8.25 (1.71)	7.50 (2.38)	7.88 (1.96)
Rate your awareness of the overall traffic situation.	8.25 (0.96)	7.25 (2.87)	7.75 (2.05)

3.1.3 General Questionnaire

The Integrated EFDI General Questionnaire elicited additional feedback from the participants after they had worked in both controller positions (see Table 4). The participants rated the readability of the text as high. They also reported that they were able to notice and correct flight data management errors and that the Integrated EFDI operated in a consistent manner. The participants thought that the Integrated EFDI would have a positive effect on their ability to control traffic in the ATCT. They commented that the interface was very user friendly and that it would help them maintain awareness of the traffic situation at a complex airport. Their greatest concern was that the Integrated EFDI may cause too much "head down" time. In other words, they were concerned that controllers may spend less time visually scanning the airport surface and surrounding airspace.

Conversely, the participants also commented that the Integrated EFDI may increase their awareness of the airport traffic situation. They were concerned that the touch sensitive display design may be difficult to use (or "fat finger" intolerant) for some controllers.

Table 4. Data for the Integrated EFDI General Questionnaire

PSQ Item	Mean (*SD*)
Rate the readability of the text. **Comments**: "Excellent." "Slight change in location of some info (i.e., Beacon Code)."	9.00 (0.82)
Rate the salience of flight data management errors. **Comments**: None.	7.25 (0.96)
Rate the effort required to correct flight data management errors. **Comments**: "Straight forward."	3.00 (1.41)
Rate the consistency of operation for the interface. That is, were actions accomplished in a consistent manner? **Comments**: None.	9.00 (0.82)
What effect do you think the Integrated EFDI will have on your ability to control traffic in the tower? **Comments**: "Concern with heads down time, but expect experience will address this issue." "Only concern may be a heads down scenario." "Very user-friendly system - easy to use and keep total traffic picture at complex airport."	7.50 (0.58)
What is the greatest benefit of the Integrated EFDI? **Comments**: "Puts all data in one spot and allows for cross check. Position and hold." "1) accuracy of data - no misspelling or bad writing on strips that can lead to a misinterpretation, 2) saves paper." "Positive control: Touch aircraft strip information - shows aircraft location on screen." "Constant feedback of position and response to control instructions."	–
What is the biggest problem with the Integrated EFDI? **Comments**: "*Fat Finger* intolerant." "Possible heads down." "Possible head down time. Audible alarm for timers. Some runway crossing feature for safety." "Data block movement via the algorithm takes getting used to. Generic timers are a little hard to evaluate as a synthetic (external and arbitrary setting) use is not part of the flow of planned actions."	–
In order of preference, what additional features would you desire for the Integrated EFDI? **Comments**: "Auto flash if not handed off correctly flashing ATIS box after change. Gate assignment." "1) A hold short indicator when Ground Control or Local Control stops an aircraft short of a point, 2) On Ground Control display the runway on an arrival inbound, 3) Ability to add a gate/location to a data block." "Audible alarm for timers. Some runway crossing feature for safety." "Flashing timer notification needs to be bolder, perhaps alternating colors."	–
Do you have any additional comments regarding the Integrated EFDI? **Comments**: "Very clean." "No." "Very good tool that would work well at medium to high level airport. Not sure about level 7 facilities and below or HUB (very high) level airports."	–

Note. Dashes indicate that quantitative data was not collected for that item.

The participants said that the greatest benefits of the Integrated EFDI is that it consolidates information, links flight data and aircraft position, provides an automatic Taxi-into-Position-and-Hold (TIPH) indicator, displays accurate data that are not subject to misspelling or poor handwriting, and provides positive control.

The participants also suggested a number of new features. They recommended adding methods to accomplish a gate assignment, hold short clearance indicator, and notification of aircraft that are occupying a runway surface. Some of the participants also suggested using an audible alert for some functions.

3.2 Perceptual-Spatial EFDI

Unlike the Integrated EFDI, the P-S EFDI does not rely on a surface surveillance system. However, it does provide a representation of the airport surface that controllers can use to spatially organize electronic flight data. Placing FDEs on the P-S EFDI is similar to the procedure controllers used with "shrimp boats" prior to the development of radar display technology. Shrimp boats were simply small tokens that controllers placed on a map surface to represent aircraft positions. However, due to the electronic nature of the P-S EFDI, it provides a number of advantages over shrimp boats. In addition to providing the ability to record traffic counts and delays, the P-S EFDI allows controllers to share information among positions to support a shared awareness of the airport traffic situation. The P-S EFDI should also reduce a controller's cognitive workload by associating an aircraft's position with its flight data.

3.2.1 Interaction Data

We collected the P-S EFDI interaction data and calculated the error rate in the same manner as for the Integrated EFDI. Table 5 shows the overall interaction data for the practice and test sessions (Appendix I shows the interaction data for each controller position).

The overall error rate for the P-S EFDI was 7% during the practice and 8% during the test. Although there was some variability between the participants in the number of actions they performed, the actions they performed most often were FDE selects and FDE repositions. Error rates for FDE selects and FDE repositions were relatively low, but probably would have improved if we had allowed more training time for the participants to become familiar with the use of the touch sensitive displays. The participants also performed position transfers quite often and with a relatively low error rate. They had the highest error rates for acknowledging an expired aircraft timer (38%), acknowledging an ATIS update indicator (26%), FDE resequencing (26%), and acknowledging an expired generic timer (25%). Like the Integrated EFDI, the touch sensitive areas for the expired aircraft timer and ATIS update indicator were too small. The participants performed 10 of the 17 actions only three times or less on average. The participants performed FDE resequencing and acknowledgment of an expired generic timer very infrequently. The participants also had relatively high error rates for the TIPH clearance (16%) and departure clearance (10%). Each of these actions required the participants to select an FDE and then select a rectangular shaped button on the touch sensitive display.

Table 5. Overall Interaction Data for the Perceptual-Spatial EFDI

	Practice			Test		
EFDI Action	**Mean (*SD*) Number of Actions**	**Mean (*SD*) Number of Misses**	**Error Rate (%)**	**Mean (*SD*) Number of Actions**	**Mean (*SD*) Number of Misses**	**Error Rate (%)**
FDE Select	174.25 (50.64)	8.00 (2.45)	4	233.25 (28.58)	11.13 (4.36)	5
FDE Reposition	169.50 (65.42)	17.00 (19.39)	9	190.63 (58.17)	14.38 (8.62)	7
FDE Resequence	1.50 (0.58)	0.75 (0.50)	33	3.13 (1.25)	1.13 (1.64)	26
List Transfer	19.00 (2.83)	0.00 (0.00)	0	24.50 (1.00)	0.00 (0.00)	0
TIPH Clearance	14.50 (4.95)	2.50 (2.12)	15	22.00 (4.32)	4.25 (1.26)	16
Departure Clearance	17.50 (0.71)	0.50 (0.71)	3	22.50 (2.38)	2.50 (1.00)	10
Position Transfer	32.75 (3.77)	2.00 (1.63)	6	41.63 (3.70)	2.25 (2.38)	5
Assign Alt. & Hdg.	0.25 (0.50)	0.00 (0.00)	0	0.25 (0.46)	0.00 (0.00)	0
Assign Altitude	0.50 (1.00)	0.00 (0.00)	0	0.63 (0.74)	0.00 (0.00)	0
Assign Heading	0.75 (0.50)	0.00 (0.00)	0	0.25 (0.46)	0.00 (0.00)	0
Ack. Assignment	1.50 (0.58)	0.25 (0.50)	14	1.13 (0.64)	0.00 (0.00)	0
Ack. Expired Generic Timer	1.00 (0.00)	0.00 (0.00)	0	1.13 (0.35)	0.38 (0.52)	25
Ack. Expired Aircraft Timer	1.00 (0.00)	0.50 (1.00)	33	1.25 (0.46)	0.75 (1.39)	38
Ack. ATIS Update Indicator	16.50 (6.19)	3.25 (3.30)	16	33.00 (6.91)	11.75 (10.95)	26
Ack. Common ATIS Update	2.00 (0.00)	0.50 (0.58)	20	2.00 (0.00)	0.13 (0.35)	6
Assign Runway	0.00 (0.00)	0.00 (0.00)	0	0.75 (1.39)	0.00 (0.00)	0
Assign Intersection	0.25 (0.50)	0.00 (0.00)	0	1.00 (0.00)	0.00 (0.00)	0
Deselect Error	4.25 (2.99)	–	–	2.50 (1.60)	–	–

Note. Dashes indicate that quantitative data was not collected for that item.

3.2.2 Post-Scenario Questionnaire

The participants completed the PSQ after each test scenario. The interface remained visible while the participants completed the PSQ, so they could refer to it if needed. Responses on the PSQ ranged from 1 (*Extremely Low*) to 10 (*Extremely High*). The pattern of responses for the ground and local controller positions were similar. Table 6 shows the mean ratings for each item by ground and local controller positions and the combined overall rating. Appendix K shows the participants' comments for each PSQ item.

Overall, the participants rated the P-S EFDI as requiring low levels of effort while still providing adequate information to maintain awareness. They reported having some trouble noticing updated ATIS information and expired generic and aircraft specific timers. The participants rated their awareness of current and projected aircraft locations as high, especially for aircraft to

which they had given a TIPH clearance. They rated their ability to notice potential runway incursions as moderate. The participants also commented that their performance probably would improve with more practice.

Table 6. Post-Scenario Questionnaire Data for the P-S EFDI

PSQ Item	Ground Mean (*SD*)	Local Mean (*SD*)	Overall Mean (*SD*)
Rate the effort needed to select FDEs.	2.25 (1.26)	1.75 (0.96)	2.00 (1.07)
Rate the effort needed to resequence FDEs.	2.00 (2.00)	2.75 (1.71)	2.38 (1.77)
Rate the effort needed to maintain FDE separation.	2.50 (0.58)	2.25 (1.26)	2.38 (0.92)
Rate your ability to detect an ATIS update.	6.00 (2.45)	6.00 (2.31)	6.00 (2.20)
Rate the salience of the FDE ATIS indicator.	5.75 (2.22)	6.00 (2.16)	5.88 (2.03)
Rate the effort needed to set the generic timer.	2.00 (0.82)	2.00 (0.82)	2.00 (0.76)
Rate the salience of an expired generic timer.	4.00 (2.16)	3.25 (1.50)	3.63 (1.77)
Rate the effort needed to set an aircraft specific timer.	2.50 (1.00)	2.25 (0.96)	2.38 (0.92)
Rate the salience of an expired aircraft specific timer.	4.00 (1.15)	4.00 (1.73)	4.00 (1.29)
Rate the adequacy of feedback for completed actions.	8.00 (0.82)	7.75 (1.71)	7.88 (1.25)
Rate the overall effort needed to use the touch screen.	3.00 (1.41)	2.25 (0.50)	2.63 (1.06)
Rate the effort needed to amend flight data.	2.00 (1.41)	1.75 (0.50)	1.88 (0.99)
Rate the salience of amended flight data.	7.50 (1.73)	8.25 (0.96)	7.88 (1.36)
Rate the effort needed to highlight flight data.	1.50 (0.58)	2.00 (1.15)	1.75 (0.89)
Rate the salience of highlighted flight data.	7.50 (1.73)	8.75 (1.26)	8.13 (1.55)
Rate the overall effort needed to maintain flight data.	2.25 (1.26)	2.50 (0.58)	2.38 (0.92)
Rate the salience of expected departure clearance time information.	8.75 (0.96)	8.75 (0.96)	8.75 (0.89)
Rate your ability to find necessary flight information.	8.75 (0.96)	8.75 (0.96)	8.75 (0.96)
Rate your ability to detect aircraft on the runway due to a TIPH clearance.	9.00 (0.82)	9.50 (0.58)	9.25 (0.71)
Rate your awareness for current aircraft locations.	7.75 (0.50)	7.00 (1.00)	7.43 (0.79)
Rate your awareness for projected aircraft locations.	7.25 (0.50)	7.75 (1.26)	7.50 (0.93)
Rate your awareness for potential runway incursions.	6.25 (3.30)	6.75 (2.75)	6.50 (2.83)
Rate your awareness of the overall traffic situation.	7.50 (1.73)	7.50 (0.58)	7.50 (1.20)

3.2.3 General Questionnaire

The P-S EFDI General Questionnaire elicited more general feedback from the participants (see Table 7). The participants reported that they were able to read the text. They were also able to notice and correct flight data management errors, but said they wanted a way to reverse actions that they performed by mistake. They rated the P-S EFDI as operating in a consistent manner. The participants also thought that the P-S EFDI would benefit their ability to control traffic from the ATCT because it presented a clear depiction of the traffic situation that would be understandable to a supervisor. The participants reported that the greatest benefits of the P-S EFDI included clarity of information, improved organization, reduced noise levels, improved memory aids, and improved cues to maintain awareness of the traffic situation. The participants

thought that the biggest problem with the P-S EFDI is that it was somewhat labor intensive. This was probably because they continuously had to move FDEs on the touch sensitive display to maintain awareness of the aircrafts' positions and the poor usability of some features, such as the ATIS update indicator. The participants were also concerned with the potential viewing angle of the interface and the creation of a head down situation. They also wanted more ways to recover from actions such as passing an FDE too soon. During the usability study, the participants discovered that there was a way to recall an FDE if they had transferred one too soon or if they had transferred the wrong FDE. However, we did not train the participants on this feature as we had not completed its design before the usability study. The participants also requested some additional features such as the ability to indicate a closed runway and make a gate assignment.

Table 7. Data for the Perceptual-Spatial EFDI General Questionnaire

PSQ Item	Mean (*SD*)
Rate the readability of the text. **Comments**: "Clean." "In this environment it is good because it is controlled lighting. What about a tower and at an angle since most will be looking down at data and from the side." "It would be nice to have adjustments." "It could be improved quite a bit."	7.75 (2.63)
Rate the salience of flight data management errors. **Comments**: "Don't happen often."	7.50 (1.29)
Rate the effort required to correct flight data management errors. **Comments**: "It would be nice to have a back or undo button for your last action. If you have quick fingers you could drag wrong aircraft."	4.50 (3.32)
Rate the consistency of operation for the interface. That is, were actions accomplished in a consistent manner? **Comments**: None.	9.00 (0.82)
What effect do you think the Perceptual-Spatial EFDI will have on your ability to control traffic in the tower? **Comments**: "Clean info. Emphasized where needed graphic presentation understandable to supervisor" "It should be a very useful tool - it provides many options and clarity of changes to data - no penmanship unreadability." "This could be a very useful tool and help eliminate coordination and distractions."	7.75 (0.50)
What is the greatest benefit of the Perceptual-Spatial EFDI? **Comments**: "Does or indicates many currently manual tasks (i.e., ATIS/Code Change). Clear understandable." "Clarity of data and information it provides to the controller." "Organization and reduced noise levels." "Using a FPS in a holder there are only a few things you can do as a memory aid. With this display movement around many places helps give many cues to maintain awareness."	–
What is the biggest problem with the Perceptual-Spatial EFDI? **Comments**: "Somewhat labor intensive. I suspect experience and verbal interface with traffic will lessen this. Boxes handy, but very (too) aggressive." "Angle at which controller will be viewing and a heads down situation." "Ability to undo errors or select wrong aircraft." "Error Recovery - If I passed an FDE to Local/Ground too soon it takes a little effort to grab it back. Proficiency would probably make this a non-factor."	–

(table continues)

Table 7 (continued). Data for the Perceptual-Spatial EFDI General Questionnaire

PSQ Item	Mean (*SD*)
In order of preference, what additional features would you desire for the Perceptual-Spatial EFDI? **Comments**: "Gate/Destination/Scratch pad. Flashing ATIS box if not addressed prior to departures. Ability to retrieve data tags." "(1) Better ATIS info, especially when code changes, (2) Ability to put closures on display (i.e., runways and taxiways to prevent takeoffs on closed surfaces, etc.), (3) Departure List for Ground Control - the last 5-6 aircraft worked should stay on display." "Some feature that highlights runway crossings." "A little more room for the Arrival FDE to be moved prior to touchdown might assist in a technique."	–
Do you have any additional comments regarding the Perceptual-Spatial EFDI? **Comments**: "Like to try with voice." "As with the ASDE - maybe gate/location information. The ability to give an aircraft from Local Control back to Ground Control if he has to return to the ramp (both this system and ASDE-X). There may be other scenarios as well, such as radar returning to Local Control or Local Control recalling because aircraft aborts takeoff or departs and immediately returns to airport for landing and never leaves the frequency."	–

Note. Dashes indicate that quantitative data was not collected for that item.

4. RECOMMENDATIONS

The interaction and questionnaire data for the Integrated and P-S EFDIs indicate a need to make a number of improvements for both EFDIs. We recommend the following changes and improvements:

1. Increase the size of the touch sensitive area for the expired generic timer.
2. Increase the size of the touch sensitive area for the aircraft specific timer.
3. Increase the size of the touch sensitive area for the ATIS update indicator.
4. Increase the height of TIPH, departure clearance, and runway/taxiway assignment buttons.
5. Ensure that the entire FDE frame remains visible at all times during resequencing on the Integrated EFDI.
6. Implement a method to retrieve an FDE that was passed to another controller position.
7. Implement a method to undo actions such as acknowledging the wrong ATIS update indicator.
8. Implement a method to provide a gate assignment for an aircraft.
9. Implement a method to indicate that a runway or taxiway is closed.
10. Implement a method to indicate that an aircraft is on a runway surface on the Integrated EFDI.
11. Implement a method to indicate that the controller has given a hold short clearance to an aircraft.

5. CONCLUSION

Overall, the EFDIs were easy to use and the participants had favorable responses. The EFDIs required little effort, provided all of the necessary flight data, and supported the controllers' awareness of the traffic situation. However, there were several functions that were difficult to use. The ability to record user interaction with the EFDIs provided useful data to help us refine the EFDI design concepts. We expect to improve the usability of the EFDIs by redesigning the elements that the participants had the most difficulty using and by addressing the participants' suggestions for additional features.

The monitoring task we used for the test focused on interface design and we were able to identify the most egregious usability problems. The overall error rate declined over time with the Integrated EFDI, but not with the P-S EFDI. It is difficult to tell whether the EFDI design, the participants' lack of experience with the touch sensitive display, or a combination of the two affected the error rate most. We recommend that future usability tests incorporate at least an additional 30-60 min of training on the touch sensitive display. Except for the simplest actions, such as touching buttons on a kiosk, most people are not proficient with touch sensitive displays. The additional training would allow more time for the participants to learn how to perform actions such as dragging. The participants would gain more experience with suboptimal viewing angles to help them recognize and prevent parallax errors. In future testing, the participants must also perform some actions more often to ensure reliable usability data.

Finally, we must recognize that the participants did not have an OTW view during this study. They had to determine aircraft position either by using the Integrated EFDI, ASDE-X display, or the TDW display. Future testing should include simulation pilots, more sophisticated ground operations, and an OTW view. The EFDI concepts tested in this study may improve the way that controllers handle flight data in the near future. The EFDI concepts may also support future concepts such as the Staffed Virtual Tower or Equivalent Visual Operations. We will need to test these and many other new concepts that will support the air traffic system of the future. Therefore, we must continue to develop our ability to simulate and test ATCT operations with a platform that supports concept research.

References

Card, S. K., Moran, T. P., & Newell, A. (1983). *The Psychology of Human-Computer Interaction.* Hillsdale, NJ: Erlbaum.

Dayton, T., McFarland, A., & Kramer, J. (1998). Bridging user needs to object oriented GUI prototype via task object design. In L. E. Wood (Ed.), *User interface design* (pp. 25-56). Boca Raton, FL: CRC Press.

Lauesen, S. (2005). *User Interface Design – A Software Engineering Perspective.* Essex, England: Pearson Education Limited.

Nielsen, J., & Mack, R. L. (1994). *Usability Inspection Methods*. New York: John Wiley & Sons, Inc.

Simmons, B., Boan, L., & Massimini, P. (2000). *Simulation analysis of dual CRDA arrival streams to runways 27 and 33L at Boston Logan International Airport* (MTR 00W0000128). McLean, VA: The MITRE Corporation, Center for Advanced Aviation System Development.

Truitt, T. R. (2006a). *Concept development and design description of electronic flight data interfaces for Airport Traffic Control Towers* (DOT/FAA/TN-06/17). Atlantic City International Airport, NJ: Federal Aviation Administration, William J. Hughes Technical Center.

Truitt, T. R. (2006b). *Electronic flight data in Airport Traffic Control Towers: Literature review* (DOT/FAA/CT-05/13). Atlantic City International Airport, NJ: Federal Aviation Administration, William J. Hughes Technical Center.

Acronyms

ASDE-X	Airport Surface Detection Equipment – Model X
ATCT	Airport Traffic Control Tower
ATIS	Automatic Terminal Information Service
DESIREE	Distributed Environment for Simulation, Rapid Engineering, and Experimentation
EFDI	Electronic Flight Data Interface
FAA	Federal Aviation Administration
FDE	Flight Data Element
FPS	Flight Progress Strip
MKE	Milwaukee Mitchell Airport
OTW	Out-the-Window
P-S	Perceptual-Spatial
PSQ	Post-Scenario Questionnaire
RDHFL	Research, Development, & Human Factors Laboratory
SD	Standard Deviation
SME	Subject Matter Expert
TDW	Tower Display Workstation
TGF	Target Generation Facility
TIPH	Taxi-into-Position-and Hold

Appendix A
Biographical Questionnaire

Participant #_____ Date _____

Biographical Questionnaire

Instructions:

This questionnaire is designed to obtain information about your background and experience as a certified professional controller (CPC). Researchers will only use this information to describe the participants in this study as a group. Your identity will remain anonymous.

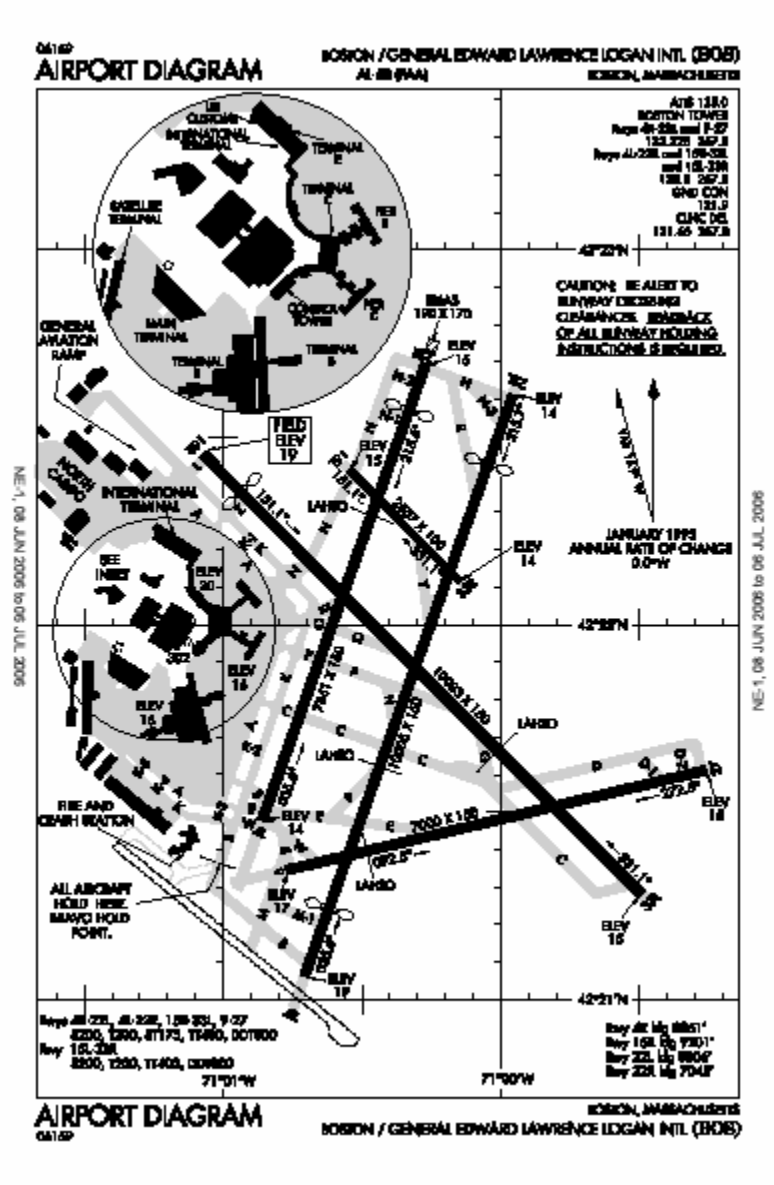
Demographic Information and Experience

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	
4. How long have you worked as a **Certified Professional Controller (include both FAA and military experience)**?	_____ years _____ months	
5. How long have you worked as a **CPC for the FAA**?	_____ years _____ months	
6. How long have you **actively controlled traffic** in an airport traffic control tower?	_____ years _____ months	
7. How many of the **past 12 months** have you actively controlled traffic in an airport traffic control tower?	_____ months	
8. Rate your current **skill as a CPC**.	Not Skilled ①②③④⑤⑥⑦⑧⑨⑩	Extremely Skilled
9. Rate your current **level of stress**.	Not Stressed ①②③④⑤⑥⑦⑧⑨⑩	Extremely Stressed
10. Rate your **level of motivation** to participate in this study.	Not Motivated ①②③④⑤⑥⑦⑧⑨⑩	Extremely Motivated

Appendix B

Taxiway Diagram of Boston/Logan International Airport (BOS)

Taxiway Diagram of Boston/Logan International Airport (BOS)



Appendix C

Informed Consent Statement

Informed Consent Statement

I, _____, understand that this study, entitled "User-centered testing of two prototype EFDI for ATCTs" is sponsored by the Federal Aviation Administration and is being directed by Dr. Todd R. Truitt.

Nature and Purpose:

I have been recruited to volunteer as a participant in this project. The purpose of the study is to determine the effects of alternative air traffic control procedures in a part-task simulation. The results of the study will be used to establish the feasibility of implementing these alternative or similar air traffic control procedures in an operational environment.

Experimental Procedures:

Terminal controllers will arrive at the RDHFL in groups of two and will participate over 2 days. Each participant will complete a flight data maintenance task at both the ground and local positions. The first day of the study will consist of a project briefing, equipment familiarization, and practice scenarios. During the second day, the participants will work multiple experimental scenarios and complete a debriefing session. The participants will work from about 8:30 AM to about 5:00 PM every day with a lunch break and at least two rest breaks.

The participants will maintain flight data under each of three different experimental procedures. The participants will also complete actions as instructed by the study facilitator. After each scenario, the participants will complete questionnaires to evaluate the impact of the alternative procedures on participant workload and acceptance. In addition, a study facilitator and log keeper will take notes during each scenario to further assess the usability of the Electronic Flight Data Interfaces (EFDIs). The simulation will be audio-video recorded in case researchers need to reexamine any important 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 I understand that no individual names or identities will be recorded, associated with data, 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 effects of alternative ATC procedures for use in airport traffic control towers. My data will help the FAA to establish the feasibility of these procedures within such an environment.

Participant Responsibilities:

I am aware that to participate in this study I must be a current or former certified professional controller in the Terminal specialty. 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 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. Truitt has adequately answered all the questions I have asked about this study, my participation, and the procedures involved. I understand that Dr. Truitt 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. Truitt at (609) 485-4351.

Compensation and Injury:

I agree to immediately report any injury or suspected adverse effect to Dr. Todd R. Truitt at (609) 485-4351. 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 D
Training Protocols

Training Protocol for the Integrated EFDI

1. General rules of operation
    a. Orientation to screen
        i. Screen is movable
        ii. Position yourself directly in front of the screen to prevent parallax
    b. Orientation of the airport surface map
        i. North is not up
        ii. ASDE-X functions preserved
            a. Map rotation
            b. Map zoom
    c. Placement of the EFD lists (Ctrl-p)
    d. Noun-Verb interaction style
        i. Select object to act upon
        ii. Select action to perform
        iii. Automatic object deselect
    e. How to select an EFD object
        i. Tap screen instead of touch and hold
        ii. Touch and hold may cause auto deselect if object is moved
    f. Touch vs. Slew
        i. Touch is for EFD interaction
        ii. Slew if for ASDE-X interaction
    g. Owned vs. Unowned
        i. Owned is white, unowned is gray
        ii. Can only change info on owned data
2. Flight Data Interaction
    a. Automatic data block offset
        i. Moving data block removes that data block from algorithm
        ii. "5" ENTER returns all data blocks to the algorithm
    b. Select FDE
    c. Select Data Block
    d. Resequence FDE
    e. Move Data Block
    f. Highlight Flight Data
    g. Change Assigned Heading
    h. Change Assigned Altitude
    i. Change Assigned Heading and Altitude
    j. Acknowledge Heading/Altitude Change
    k. ATIS update
        i. System area
        ii. FDE
    l. Generic Timer
        i. Set
        ii. Monitor
        iii. Acknowledge Expired Timer
    m. Aircraft Specific Timer
        i. Set
        ii. Monitor
        iii. Acknowledge
    n. Change Runway/Intersection Assignment
    o. Transfer FDE

Training Protocol for the Perceptual-Spatial EFDI

1. General rules of operation
    a. Orientation to screen
        i. Screen is movable
        ii. Position yourself directly in front of the screen to prevent parallax
    b. Orientation of the airport surface map
        i. North is not up
        ii. Map can't be changed
    c. Noun-Verb interaction style
        i. Select object to act upon
        ii. Select action to perform
        iii. Automatic object deselect
    d. How to select an EFD object
        i. Tap screen instead of touch and hold
        ii. Touch and hold may cause auto deselect if object is moved
    e. Owned vs. Unowned
        i. Owned is white, unowned is gray
        ii. Can only change info on owned data
    f. Ground & Local displays are linked
2. Flight Data Interaction
    a. Select FDE
    b. Operation of Zones
    c. Resequence FDE
    d. Highlight Flight Data
    e. Change Assigned Heading
    f. Change Assigned Altitude
    g. Change Assigned Heading and Altitude
    h. Acknowledge Heading/Altitude Change
    i. ATIS update
        i. System area
        ii. FDE
    j. Generic Timer
        i. Set
        ii. Monitor
        iii. Acknowledge Expired Timer
    k. Aircraft Specific Timer
        i. Set
        ii. Monitor
        iii. Acknowledge
    l. Change Runway/Intersection Assignment
    m. TIPH
    n. Departure Clearance
    o. Transfer FDE

Appendix E
Scripted Actions

Scripted Actions

Time (mm:ss)	Action
05:00	Highlight flight data
10:00	Change assigned heading or altitude & acknowledge
15:00	Assign intersection departure
20:00	Set generic timer for 2 min and acknowledge when expires
25:00	Set aircraft specific timer for 2 min and acknowledge when expires

Appendix F

Post-Scenario Questionnaire

Post-Scenario Questionnaire

Instructions:

Please answer the following questions based upon your experience in the scenario just completed. Your identity will remain anonymous.

1. Rate the **effort needed to select flight data elements (FDEs)** during this scenario.	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High

Comments:

_____

_____

_____

2. Rate the **effort needed to select data blocks** during this scenario.	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High

Comments:

_____

_____

_____

3. Rate the **effort needed to resequence FDEs** during this scenario.	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High

Comments:

_____

_____

_____

4. Rate the **effort needed to maintain data block separation** during this scenario.	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High

Comments:

_____

_____

5. Rate your **ability to detect an ATIS update** during this scenario.	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High

Comments:

_____

_____

_____

6. Rate the **salience of the FDE ATIS indicator** during this scenario.	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High

Comments:

_____

_____

_____

7. Rate the **effort needed to set the generic timer** during this scenario.	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High

Comments:

_____

_____

_____

8. Rate the **salience of an expired generic timer** during this scenario.	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High

Comments:

_____

_____

_____

9. Rate the **effort needed to set an aircraft specific timer** during this scenario.	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High

Comments:

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_____

10. Rate the **salience of an expired aircraft specific timer** during this scenario.	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High

Comments:

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_____

11. Rate the **adequacy of feedback for completed actions** during this scenario.	Extremely Poor	①②③④⑤⑥⑦⑧⑨⑩	Extremely Good

Comments:

_____

_____

_____

12. Rate the **overall effort needed to use the touch screen** during this scenario.	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High

Comments:

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13. Rate the **effort needed to amend flight data** during this scenario.	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High

Comments:

_____

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14. Rate the **salience of amended flight data** during this scenario.	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High

Comments:

_____

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_____

15. Rate the **effort needed to highlight flight data** during this scenario**.**	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High

Comments:

_____

_____

_____

16. Rate the **salience of highlighted flight data** during this scenario**.**	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High

Comments:

_____

_____

_____

17. Rate the **overall effort needed to maintain flight data** during this scenario.	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High

Comments:

_____

_____

_____

18. Rate the **salience of expected departure clearance time information.**	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High

Comments:

_____

_____

_____

19. Rate your **ability to find necessary flight information** during this scenario.	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High

Comments:

_____

_____

_____

20. Rate your **ability to detect aircraft on the runway due to a TIPH clearance** during this scenario.	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High

Comments:

_____

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_____

21. Rate your **awareness for current aircraft locations** during this scenario.	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High

Comments:

_____

_____

_____

22. Rate your **awareness for projected aircraft locations** during this scenario.	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High

Comments:

_____

_____

_____

23. Rate your **awareness for potential runway incursions** during this scenario.	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High

Comments:

_____

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_____

24. Rate your **awareness of the overall traffic situation** during this scenario.	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High

Comments:

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_____

25. Do you have any additional comments or clarifications about your experience using the interface during this scenario?

_____

_____

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_____

Appendix G

Integrated EFDI General Questionnaire

Integrated EFDI General Questionnaire

Instructions:

Please answer the following questions based upon your overall experience in the usability test you just completed. Your identity will remain anonymous.

Regarding the ***Integrated EFDI*** (ASDE-X combined with electronic flight data):

1. Rate the **readability of the text**.	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High

Comments:

_____

_____

_____

2. Rate the **salience of flight data management errors.**	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High

Comments:

_____

_____

_____

3. Rate the **effort required to correct flight data management errors.**	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High

Comments:

_____

_____

_____

4. Rate the **consistency of operation** for the interface. That is, were actions accomplished in a consistent manner?	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High

Comments:

_____

_____

_____

5. What effect do you think the Integrated EFDI will have on your ability to control traffic in the tower?	Negative Effect	①②③④⑤⑥⑦⑧⑨ | None	Positive Effect

Comments:

_____

_____

_____

6. What is the greatest benefit of the Integrated EFDI?

_____

_____

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7. What is the biggest problem with the Integrated EFDI?

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8. In order of preference, what additional features would you desire for the Integrated EFDI?

9. Do you have any additional comments regarding the Integrated EFDI?

Appendix H

Perceptual-Spatial EFDI General Questionnaire

Participant # _____ Date _____

Perceptual-Spatial EFDI General Questionnaire

Instructions:

Please answer the following questions based upon your overall experience in the usability test you just completed. Your identity will remain anonymous.

Regarding the ***Perceptual-Spatial EFDI*** (electronic flight data without integration of ASDE-X):

1. Rate the **readability of the text**.	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High

Comments:

_____

_____

_____

2. Rate the **salience of flight data management errors.**	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High

Comments:

_____

_____

_____

3. Rate the **effort required to correct flight data management errors.**	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High

Comments:

_____

_____

_____

Participant # _____ Date _____

4. Rate the **consistency of operation** for the interface. That is, were actions accomplished in a consistent manner?	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High

Comments:

_____

_____

_____

5. What effect do you think the Perceptual-Spatial EFDI will have on your ability to control traffic in the tower?	Negative Effect	①②③④⑤⑥⑦⑧⑨ | None	Positive Effect

Comments:

_____

_____

_____

6. What is the greatest benefit of the Perceptual-Spatial EFDI?

_____

_____

_____

_____

_____

7. What is the biggest problem with the Perceptual-Spatial EFDI?

_____

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_____

Participant # _____ Date _____

8. In order of preference, what additional features would you desire for the Perceptual-Spatial EFDI?

_____

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_____

9. Do you have any additional comments regarding the Perceptual-Spatial EFDI?

_____

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Appendix I

Complete Interaction Data for the Integrated and P-S EFDIs

Interaction Data for the Integrated EFDI Ground Controller Position

	Practice			Test		
EFDI Action	**Mean (*SD*) Number of Actions**	**Mean (*SD*) Number of Misses**	**Error Rate (%)**	**Mean (*SD*) Number of Actions**	**Mean (*SD*) Number of Misses**	**Error Rate (%)**
Data Block Select	57.50 (38.89)	3.50 (4.95)	6	95.50 (62.61)	4.00 (3.27)	4
FDE Select	51.00 (29.70)	6.00 (5.66)	11	58.00 (26.68)	8.50 (7.85)	13
FDE Resequence	5.00 (2.83)	0.00 (0.00)	0	5.75 (4.86)	0.50 (1.00)	8
Reposition Data Block	15.00 (7.07)	0.50 (0.71)	3	46.00 (36.24)	3.75 (2.50)	8
List Transfer	21.00 (0.00)	0.50 (0.71)	2	24.75 (0.96)	1.50 (1.00)	6
Position Transfer	36.50 (0.71)	8.50 (2.12)	19	43.50 (2.52)	2.75 (0.50)	6
Assign Alt. & Hdg.	1.00 (0.00)	0.00 (0.00)	0	0.00 (0.00)	0.00 (0.00)	0
Assign Altitude	0.50 (0.71)	0.00 (0.00)	0	0.50 (0.58)	0.00 (0.00)	0
Assign Heading	2.50 (3.54)	0.00 (0.00)	0	0.50 (0.58)	0.00 (0.00)	0
Ask. Assignment	3.50 (3.54)	0.50 (0.71)	13	1.00 (0.00)	0.00 (0.00)	0
Ack. Expired Generic Timer	1.50 (0.71)	3.00 (0.00)	67	1.25 (0.50)	1.50 (1.29)	55
Ack. Expired Aircraft Timer	3.00 (0.00)	4.50 (3.54)	60	2.75 (1.26)	3.25 (4.57)	54
Ack. ATIS Update Indicator	21.50 (0.71)	24.50 (9.19)	53	27.75 (4.43)	12.25 (7.97)	31
Ack. Common ATIS Update	2.00 (0.00)	0.00 (0.00)	0	2.00 (0.00)	0.50 (1.00)	20
Assign Runway	1.00 (1.41)	0.00 (0.00)	0	1.75 (1.26)	0.50 (0.58)	22
Assign Intersection	0.50 (0.71)	0.00 (0.00)	0	1.75 (2.22)	0.50 (1.00)	22
Deselect Error	2.50 (0.71)	n/a	n/a	2.50 (1.29)	n/a	n/a

Note: Overall error rate was 19% for practice and 11% for test.

Interaction Data for the Integrated EFDI Local Controller Position

	Practice			Test		
EFDI Action	**Mean (*SD*) Number of Actions**	**Mean (*SD*) Number of Misses**	**Error Rate (%)**	**Mean (*SD*) Number of Actions**	**Mean (*SD*) Number of Misses**	**Error Rate (%)**
Data Block Select	62.00 (62.23)	4.50 (4.95)	7	74.00 (53.89)	5.50 (3.11)	7
FDE Select	27.50 (21.92)	1.00 (1.41)	4	59.00 (27.34)	3.75 (4.50)	6
FDE Resequence	1.50 (0.71)	0.50 (0.71)	25	12.25 (13.72)	1.75 (2.06)	13
Reposition Data Block	24.00 (21.21)	2.00 (0.00)	8	37.00 (28.25)	6.25 (6.50)	14
Position Transfer	34.00 (0.00)	3.00 (1.41)	8	42.50 (2.65)	6.75 (1.89)	14
Assign Alt. & Hdg	0.50 (0.71)	0.00 (0.00)	0	0.50 (0.58)	0.00 (0.00)	0
Assign Altitude	0.50 (0.71)	0.00 (0.00)	0	0.50 (0.58)	0.00 (0.00)	0
Assign Heading	1.00 (1.41)	0.00 (0.00)	0	4.50 (7.72)	0.25 (0.50)	5
Ack. Assignment	4.00 (4.24)	0.00 (0.00)	0	5.25 (7.23)	0.25 (0.50)	5
Ack. Expired Generic Timer	1.50 (0.71)	4.00 (1.41)	73	1.00 (0.00)	0.25 (0.50)	20
Ack. Expired Aircraft Timer	3.50 (2.12)	11.00 (14.14)	76	1.50 (1.00)	1.00 (0.82)	40
Ack.ATIS Update Indicator	13.00 (16.97)	1.00 (1.41)	7	25.50 (7.85)	13.75 (7.09)	35
Ack. Common ATIS Update	2.00 (0.00)	0.50 (0.71)	20	2.00 (0.00)	0.75 (0.96)	27
Assign Runway	2.50 (2.12)	1.00 (0.00)	29	1.00 (1.15)	0.25 (0.50)	20
Assign Intersection	3.00 (4.24)	1.00 (0.00)	25	2.00 (2.00)	0.50 (0.58)	20
Deselect Error	0.00	n/a	n/a	1.25 (1.26)	n/a	n/a

Note: Overall error rate was 14% for practice and 13% for test

.

Interaction Data for the Perceptual Spatial EFDI Ground Controller Position

	Practice			Test		
EFDI Action	**Mean (*SD*) Number of Actions**	**Mean (*SD*) Number of Misses**	**Error Rate (%)**	**Mean (*SD*) Number of Actions**	**Mean (*SD*) Number of Misses**	**Error Rate (%)**
FDE Select	148.50 (6.36)	7.50 (3.54)	5	243.50 (35.65)	11.75 (4.79)	5
FDE Reposition	145.50 (4.95)	9.00 (8.49)	6	235.00 (50.07)	20.50 (7.85)	8
FDE Resequence	1.50 (0.71)	0.50 (0.71)	25	3.50 (1.00)	0.75 (0.50)	18
List Transfer	19.00 (2.83)	0.00 (0.00)	0	24.50 (1.00)	0.00 (0.00)	0
Position Transfer	32.50 (6.36)	1.00 (1.41)	3	43.00 (4.57)	2.25 (2.63)	5
Assign Alt. & Hdg.	0.50 (0.71)	0.00 (0.00)	0	0.25 (0.50)	0.00 (0.00)	0
Assign Altitude	1.00 (1.41)	0.00 (0.00)	0	0.75 (0.96)	0.00 (0.00)	0
Assign Heading	0.50 (0.71)	0.00 (0.00)	0	0.25 (0.50)	0.00 (0.00)	0
Ack. Assignment	1.50 (0.71)	0.50 (0.71)	25	0.75 (0.50)	0.00 (0.00)	0
Ack. Expired Generic Timer	1.00 (0.00)	0.00 (0.00)	0	1.00 (0.00)	0.25 (0.50)	20
Ack. Expired Aircraft Timer	1.00 (0.00)	1.00 (1.41)	50	1.25 (0.50)	1.25 (1.89)	50
Ack. ATIS Update Indicator	21.00 (1.41)	3.50 (4.95)	14	33.75 (4.03)	5.50 (3.32)	14
Ack. Common ATIS Update	2.00 (0.00)	1.00 (0.00)	33	2.00 (0.00)	0.25 (0.50)	11
Assign Runway	0.00 (0.00)	0.00 (0.00)	0	0.00	0.00 (0.00)	0
Assign Intersection	0.00 (0.00)	0.00 (0.00)	0	1.00 (0.00)	0.00 (0.00)	0
Deselect Error	3.50 (4.95)	n/a	n/a	1.75 (1.50)	n/a	n/a

Note: Overall error rate was 6% for practice and 7% for test.

Interaction Data for the Perceptual Spatial EFDI Local Controller Position

	Practice			Test		
EFDI Action	**Mean (*SD*) Number of Actions**	**Mean (*SD*) Number of Misses**	**Error Rate (%)**	**Mean (*SD*) Number of Actions**	**Mean (*SD*) Number of Misses**	**Error Rate (%)**
FDE Select	200.00 (70.71)	8.50 (2.12)	4	223.00 (18.85)	10.50 (4.51)	4
FDE Reposition	193.50 (102.53)	25.00 (28.28)	11	146.26 (11.67)	8.25 (3.40)	5
FDE Resequence	1.50 (0.71)	1.00 (0.00)	40	2.75 (1.50)	1.50 (2.38)	35
TIPH Clearance	14.50 (4.95)	2.50 (2.12)	15	22.00 (4.32)	4.25 (1.26)	16
Departure Clearance	17.50 (0.71)	0.50 (0.71)	3	22.50 (2.38)	2.50 (1.00)	10
Position Transfer	33.00 (1.41)	3.00 (1.41)	8	42.50 (3.00)	2.25 (2.50)	5
Assign Alt. & Hdg.	0.00 (0.00)	0.00 (0.00)	0	0.25 (0.50)	0.00 (0.00)	0
Assign Altitude	0.00 (0.00)	0.00 (0.00)	0	0.50 (0.58)	0.00 (0.00)	0
Assign Heading	1.00 (0.00)	0.00 (0.00)	0	0.25 (0.50)	0.00 (0.00)	0
Ack. Assignment	1.50 (0.71)	0.00 (0.00)	0	1.50 (0.58)	0.00 (0.00)	0
Ack. Expired Generic Timer	1.00 (0.00)	0.00 (0.00)	0	1.25 (0.50)	0.50 (0.58)	29
Ack. Expired Aircraft Timer	1.00 (0.00)	0.00 (0.00)	0	1.25 (0.50)	0.25 (0.50)	17
Ack. ATIS Update Indicator	12.00 (5.66)	3.00 (2.83)	20	32.25 (9.67)	18.00 (12.83)	36
Ack. Common ATIS Update	2.00 (0.00)	0.00 (0.00)	0	2.00 (0.00)	0.00 (0.00)	0
Assign Runway	0.00 (0.00)	0.00 (0.00)	0	1.50 (1.23)	0.00 (0.00)	0
Assign Intersection	0.50 (0.71)	0.00 (0.00)	0	1.00 (0.00)	0.00 (0.00)	0
Deselect Error	5.00 (0.00)	n/a	n/a	3.25 (1.50)	n/a	n/a

Note: Overall error rate was 8% for practice and 9% for test.

Appendix J

Post-Scenario Questionnaire Comments for the Integrated EFDI

1) Rate the effort needed to select FDEs during this scenario.
Comments: "A bit hard to hit ATIS box… both ATIS code change and aircraft specific"; "per participant comments same as run number one"; "Very easy to select and read info."

2) Rate the effort needed to select data blocks during this scenario.
Comments:

3) Rate the effort needed to resequence FDEs during this scenario.
Comments: "Appears position extremely tight. Initial selection difficult"; "They occasionally disappeared during the dragging and ended up out of sequence."

4) Rate the effort needed to maintain data block separation during this scenario.
Comments: "I like moving blocks myself to indicate which runway aircraft was taxiing to or if they were inbound to the ramp."

5) Rate your ability to detect an ATIS update during this scenario.
Comments: "Flash could be brighter."

6) Rate the salience of the FDE ATIS indicator during this scenario.
Comments: "If list is on right it is slightly more difficult than if list is on left of display"; "Needed more on Ground Control."

7) Rate the effort needed to set the generic timer during this scenario.
Comments:

8) Rate the salience of an expired generic timer during this scenario.
Comments: "If list is on right it is slightly more difficult than if list is on left of display"; "Their symbol may need to be a little larger or have soft alarm tone."

9) Rate the effort needed to set an aircraft specific timer during this scenario.
Comments: "May need this function to carry over to another position (i.e., Local Controller) when set."

10) Rate the salience of an expired aircraft specific timer during this scenario.
Comments: "If list is on right it is slightly more difficult than if list is on left of display."

11) Rate the adequacy of feedback for completed actions during this scenario.
Comments: "When completing an action, the FDE disappears but no way to confirm where you sent it. Not necessarily a problem, just need to get used to it"; "Answered [previously]."

12) Rate the overall effort needed to use the touch screen during this scenario
Comments: "Position seems tight. Possible that experience would improve targeting of touch."

13) Rate the effort needed to amend flight data during this scenario.
Comments: "May consider having canned or standard headings available on display for easy access - no need to type these in"; "Answered previous."

14) Rate the salience of amended flight data during this scenario.
Comments:

15) Rate the effort needed to highlight flight data during this scenario.
Comments:

16) Rate the salience of highlighted flight data during this scenario.
Comments:

17) Rate the overall effort needed to maintain flight data during this scenario.
Comments:

18) Rate the salience of expected departure clearance time information.
Comments: "As with any element the salience may be high initially, but information or a marker/highlight not used becomes accentuated into the background and loses its salience. We didn't ever make use of the EDCTs"; "Same as my local comments, unused data however salient is quickly tuned out by accommodation."

19) Rate your ability to find necessary flight information during this scenario.
Comments:

20) Rate your ability to detect aircraft on the runway due to a TIPH clearance during this scenario.
Comments: "Computer seemed a little slow to display TIPH aircraft"; "System indicator seemed slow to display."

21) Rate your awareness for current aircraft locations during this scenario.
Comments: "Occasionally difficult due to high volume of traffic. Data Blocks may be on different sides of display and therefore appear to be for another aircraft."

22) Rate your awareness for projected aircraft locations during this scenario.
Comments:

23) Rate your awareness for potential runway incursions during this scenario.
Comments: "Just not sure if aircraft were going to stop at the runway during taxi, etc…"

24) Rate your awareness of the overall traffic situation during this scenario.
Comments: "I did "outbound" aircraft before they started to taxi. Corrected this habit mid problem."

25) Do you have any additional comments or clarifications about your experience using the interface during this scenario?

Comments: "Started session reorganizing "outbound" list top - bottom. Reverted to automated bottom - top. ATIS change more apparent by box than text ???/ color. Should look at timer complete alert. Also maybe touch anywhere on screen to deselect function." "As became busy less important to organize more than next 3-4 Deps. Somehow N8980F in Dep. list Don't remember departing"; "I like this system a little better than yesterday's - it seems to have a little more information and be a little less labor intensive"; "I think this interface lends itself to being used during actual voice transmissions and enhances awareness and maintains focus and flow of tasks"; "Seems very good. Ground Control is a little more tedious as the time between actions is longer."

Appendix K

Post-Scenario Questionnaire Comments for the P-S EFDI

1) Rate the effort needed to select FDEs during this scenario.
Comments: “Very easy”; “It seemed that on first touch (especially the arrivals) they weren't acquiring quite as easy”; “If two data tags are next to each other make sure right tag is selected”

2) Rate the effort needed to select data blocks during this scenario.
Comments:

3) Rate the effort needed to resequence FDEs during this scenario.
Comments: “Very easy”; “I wonder about head down time vs. out the window”

4) Rate the effort needed to maintain data block (FDE) separation during this scenario.
Comments:

5) Rate your ability to detect an ATIS update during this scenario.
Comments: “Can't easily detect, experience may help”; “Needs attention either me or the system”; “Still need something more to help indicate a change”; “Boxes popping up indicate ATIS has changed and action is needed”; “The system area is just not on my scan. I only noticed the aircraft ATIS boxes. The Ground Controllers call out of a new ATIS was my only wakeup otherwise”

6) Rate the salience of the FDE ATIS indicator during this scenario.
Comments: “Not a high vis item”; “It was good yet I was not as aware of that as other reminders i.e., colored or flashing”

7) Rate the effort needed to set the generic timer during this scenario.
Comments:

8) Rate the salience of an expired generic timer during this scenario.
Comments: “If time to remember then OK. If not can overlook”; “Small audio alarm may help”; “My eyes were rarely on the system area and change there were missed. But the renewed ATIS box on the FDE was great”

9) Rate the effort needed to set an aircraft specific timer during this scenario.
Comments: “Very easy to use”

10) Rate the salience of an expired aircraft specific timer during this scenario.
Comments: “Not obvious. Maybe different color/positive to negative, etc.”

11) Rate the adequacy of feedback for completed actions during this scenario.
Comments: “This was better on Local Control when placing aircraft into the DEP CLR - then you see in the Dep List - it gives feedback instead of just disappearing”

12) Rate the overall effort needed to use the touch screen during this scenario
Comments: “Some *"fat finger*" but improving with experience”; “See question number 1”; “Very easy to use”

13) Rate the effort needed to amend flight data during this scenario.
Comments: "Very easy"

14) Rate the salience of amended flight data during this scenario.
Comments: "Better than system area info"

15) Rate the effort needed to highlight flight data during this scenario.
Comments:

16) Rate the salience of highlighted flight data during this scenario.
Comments:

17) Rate the overall effort needed to maintain flight data during this scenario.
Comments:

18) Rate the salience of expected departure clearance time information.
Comments:

19) Rate your ability to find necessary flight information during this scenario.
Comments:

20) Rate your ability to detect aircraft on the runway due to a TIPH clearance during this scenario.
Comments: "This works extremely well"; "I was not watching that, but as I looked it was always obvious"

21) Rate your awareness for current aircraft locations during this scenario.
Comments: "Makes it easier if data blocks are offset on taxiway when transferred from Ground Control, i.e., 27 departs to the left and 33L departs to the right"; "Arrivals were hard to keep track of until they were rolling out. The radar and ASDE has a gap"

22) Rate your awareness for projected aircraft locations during this scenario.
Comments: "A little lower than local control"

23) Rate your awareness for potential runway incursions during this scenario.
Comments: "Just have to be careful with heads down situations"; "Without working the aircraft it's hard to understand TIPH vs. landing aircraft or aircraft crossing down field"; "If controller does not keep up with this system, then it would be little help"; "I used the arrival FDE to position the inbound by the threshold thus preventing a possible TIPH in front of it"

24) Rate your awareness of the overall traffic situation during this scenario.
Comments: "Experience would definitely improve"

25) Do you have any additional comments or clarifications about your experience using the interface during this scenario?

Comments: “Functions well. Scenario does provide unexpected issues i.e., B717 exit points. ATIS change needs work Maybe if departures reach runway without ATIS cleared, have box flash.”; “Found out couldn't resequence when transitioned to local outside box. Can remove from ramp control?”; “Slightly more cumbersome than when using through ASDE-X”; “Outstanding stuff at this point!”; “Data block overlap and having quick fingers could lead to selecting the wrong aircraft. A BACK button might be useful”; “Much smoother after using the equipment more”; “I found myself using the FDE to move them subtly from place to place to make me aware of who was clear of whom and who was a potential conflict and potential resequence. I felt the system was very useful”; “Practice makes things better or the more I practice the luckier I get”