INITIAL USABILITY TEST OF NEW CONCEPTS FOR ELECTRONIC FLIGHT DATA HANDLING IN AIRPORT TRAFFIC CONTROL TOWERS

Todd R. Truitt, Ph.D.
FAA Human Factors Team – Atlantic City
Research, Development, & Human Factors
Laboratory, Building 28
Atlantic City International Airport, NJ 08405
(609) 485-4351
todd.truitt@faa.gov

Robert V. Muldoon
Northrop Grumman IT
Research, Development, & Human Factors
Laboratory, Building 28
Atlantic City International Airport, NJ 08405
(609) 485-7017
robert.ctr.muldoon@faa.gov

This paper summarizes the results from a usability test of two prototype Electronic Flight Data Interfaces (EFDIs) for Airport Traffic Control Towers (ATCTs). We conducted a part-task simulation of airport surface operations, including local and ground controller positions, and assessed participant performance and feedback. We present the usability test procedure and results of subjective and objective measures. We also provide recommendations for improving the EFDIs.

Introduction

According to the Federal Aviation Administration (FAA), airport operations at the 517 Airport Traffic Control Towers (ATCTs) are projected to increase from 63.1 million in 2004 to 68.8 million in 2008 (FAA, 2005). Therefore, we must find ways to improve the efficiency and safety of the National Airspace System (NAS). Controllers currently use paper Flight Progress Strips (FPSs) in ATCT tasks. FPSs inherently limit the efficiency and usefulness of flight data because controllers must manually update the information contained on them and physically pass the FPSs from one controller to another. FPS information that controllers add or change does not enter the NAS computer systems; this restricts the controllers' ability to communicate flight data information with other controllers and facilities. Currently, controllers must perform most communication and coordination between the ATCT and other facilities via landline.

Members of the FAA Human Factors Team – Atlantic City have developed two prototype Electronic Flight Data Interfaces (EFDIs) to help controllers manage physical and cognitive workload associated with flight data management (see Truitt, 2006). The EFDI designs should also improve awareness of safety-critical situations.

The Integrated EFDI combines electronic flight data with an airport surface surveillance capability (see Figure 1). It 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).

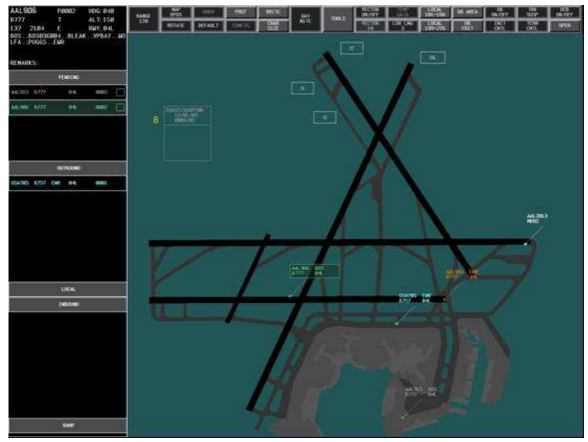

Figure 1. An overview of the Integrated EFDI.

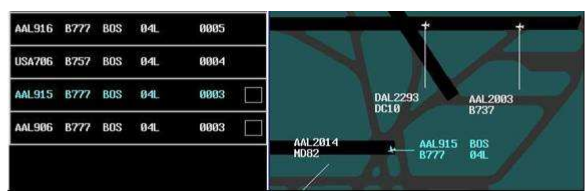

Figure 2. FDEs and data blocks on the Integrated EFDI.

The Perceptual-Spatial (P-S) EFDI presents electronic flight data along with an airport surface map that provides a spatial anchor for FDEs (see Figure 3). The P-S EFDI does not rely on surface surveillance, but facilitates memory for aircraft position through the controllers' movement of the FDEs (see Figure 4).

Both EFDIs accommodate the local and ground controller positions with touch-sensitive displays that link to one another, so that controllers can easily share information. The EFDIs automate most FPS marking, integrate information into a single display, and provide new tools (e.g., timing information) for controllers. We anticipate that the EFDIs will decrease ATCT controller workload, decrease the need for shifts of visual attention, and improve the ability to prevent runway incursions. However, we must test the concepts appropriately to ensure their effectiveness.

Figure 3. An overview of the P-S EFDI.

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

This paper reports the initial usability test results for the EFDIs. The results provide an initial estimate of (a) effort required to learn to use the EFDIs, (b) effort required to use the touch-sensitive display, and (c) objective error rates.

Method

We collected data during a part-task simulation that required the participants to monitor an airport traffic situation, as they simultaneously managed all of the associated flight data using one of the EFDIs.

Participants

Four supervisory-level controllers participated in groups of two. All four participants were highly experienced ATCT controllers (M = 17.9 yrs, SD = 6.9 yrs).

Equipment

We used a VarTech Systems, Inc. 21.3″ touch-sensitive display. The display has an active display 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 degrees. Resistive technology enables the user to activate the display with either a stylus or a person's fingertip. We mounted the 30.4 lb (13.8 kg) display on a stand that allows the user to adjust the horizontal and vertical viewing angle. A Cortron, Inc. keyboard (Model-549) and trackball/keypad (Model-580) served as additional input devices. Figure 5 shows the hardware used to implement the prototype EFDIs.

Figure 5. Hardware used to implement the prototype EFDIs.

We presented prerecorded airport traffic scenarios using off-the-shelf computers and our own air traffic simulator, the Distributed Environment for Simulation, Rapid Engineering, and Experimentation (DESIREE). DESIREE receives dynamic aircraft data from the Target Generation Facility and then displays that information to the controller via one of the EFDIs.

Airport Traffic Scenarios

Two Subject Matter Experts (SMEs) created traffic scenarios for Boston/Logan International airport using a 27/33 runway configuration. This configuration provides several prototypical characteristics that are of general interest. For example, both simple and complex taxi routes are available, and there are crossing and parallel runways.

We used one 30-min base traffic scenario for training and practice and one 30-min base traffic scenario for testing. The training and practice scenario began without any aircraft on the airport surface. The testing scenario began with aircraft occupying the airport as if the participant had taken over the controller position between shifts. We created different versions of the same scenario by modifying all of the aircraft call signs in the base scenarios to create different versions of the same scenario. In effect, the participants experienced the exact same scenario during each of the training and practice and testing sessions, respectively. Based on the findings of Simmons, Boan, and Massimini (2000), the SMEs designed each scenario with an arrival/departure rate of 40 aircraft per hour; there were approximately three departures for every arrival. The scenarios distributed aircraft among the primary crossing runways, 27 and 33L, and the secondary parallel runway, 33R.

Procedure

We counterbalanced the order of EFDI presentation (i.e., Integrated vs. P-S). For each EFDI, the participants received a 30-min training session and then completed a 30-min practice session. An experimenter conducted the training using a structured protocol. Two 30-min test sessions followed in which the participants switched control positions (ground vs. local) at the end of the first test session. During the test sessions, the participants monitored traffic and performed all necessary flight data management. 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 surface surveillance and short-range radar. At 5-min intervals, the experimenter instructed the participants to perform predefined tasks as workload permitted. This was necessary to ensure that the participants performed all of the possible actions at least once during testing. The participants responded to questionnaires, following each test session. We recorded audio and video data during all sessions. After completing both test sessions for an EFDI, the participants responded to an additional questionnaire and provided feedback during an interview. We then repeated the entire procedure for the alternate EFDI.

Results

To calculate an error rate for each EFDI action, we divided the mean number of touch-screen misses (*M*) by the sum of *M* and the mean number of successes (*S*), or total attempts. The participants were able to complete all of the required EFDI actions, and we did not observe any task failures during the test scenarios.

Integrated EFDI

For the Integrated EFDI, the participants had an overall error rate of 16% during the practice and 12% during the test. Table 1 shows the overall (ground and local controller data combined) Integrated EFDI interaction data for the test scenarios.

Table 1. Interaction Data for the Integrated EFDI

EFDI Action	**Mean (*SD*) Number of Actions**	**Mean (*SD*) Number of Misses**	**Error Rate**
Data Block Select	84.75 (55.29)	4.75 (3.06)	5%
FDE Select	58.50 (25.01)	6.13 (6.45)	9%
FDE Resequence	9.00 (10.14)	1.13 (1.64)	11%
Reposition Data Block	41.50 (30.46)	5.00 (4.75)	11%
List Transfer	24.75 (0.96)	1.50 (1.00)	6%
Position Transfer	43.00 (2.45)	4.75 (2.49)	10%
Assign Alt. & Hdg.	0.25 (0.46)	0.00 (0.00)	0%
Assign Altitude	0.50 (0.53)	0.00 (0.00)	0%
Assign Heading	2.50 (5.50)	0.13 (0.35)	5%
Ack. Assignment	3.13 (5.25)	0.13 (0.35)	4%
Ack. Expired Generic Timer	1.13 (0.35)	0.88 (1.13)	44%
Ack. Expired Aircraft Timer	2.13 (1.25)	2.13 (3.27)	50%
Ack.ATIS Update Indicator	26.63 (6.02)	13.00 (7.03)	33%
Ack. Common ATIS Update	2.00 (0.00)	0.63 (0.92)	24%
Assign Runway	1.38 (1.19)	0.38 (0.52)	21%
Assign Intersection	1.88 (1.96)	0.50 (0.76)	21%

Although there was a great deal of variability between the participants, they performed data block selections more often than any other action. The participants could select flight data by either selecting a data block or a flight data element (FDE). Rather than searching through the list of FDEs along the side of the display to find flight data, the participants preferred to select the data block positioned on the airport surface map of the display. The choice to select a data block more often than an FDE suggests that there is an advantage to correlating flight data with aircraft position. The participants may have also preferred to select a data block because it resulted in fewer missed actions and a lower error rate (5% vs. 9%). This finding suggests that perhaps the FDEs were too small. Selecting a data block appeared to be a better method of selecting flight data; however, a data block selection error 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 (Raskin, 2000). 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 is automatically deselected. We chose this sequence of actions to reduce input error and to provide feedback to the user when an action has taken place. However, because the Integrated EFDI allows the user to select flight data via the data blocks and FDEs for reasons other than to take an action (e.g., looking at a 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 performed 9 of the 16 actions only three times or less on average. These infrequently performed actions also had some of the highest error rates. The participants had the highest error rate when acknowledging an expired generic and 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. The participants also had a high error rate for acknowledging the Automatic Terminal Information Service (ATIS) update indicator (33%). The touch-sensitive area of the ATIS update indicator was the same size as that used for the expired aircraft timer. Assigning runway and intersection assignments also occurred infrequently, but had high error rates (21%). When resequencing FDEs, participants had an error rate of 11%. During the usability test, we discovered 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 and drag an FDE to another location. The participants completed list transfers and controller position transfers by selecting an FDE or data block and then selecting the appropriate header (i.e., ground, departure, etc.). The participants had an error rate of 6% for list transfers and an error rate of 10% for position transfers.

The participants also provided subjective ratings of the Integrated EFDIs using a 10-point Likert scale (1 = extremely low; 10 = extremely high) for eight questionnaire items (see Table 2).

Table 2. Post-Scenario Questionnaire Ratings for the Integrated EFDI

Questionnaire Item	**Mean (*SD*)**
Effort to use touch-sensitive display	2.6 (1.7)
Effort to maintain flight data	2.0 (0.8)
Readability of text	9.0 (0.8)
Ability to find necessary flight info	7.9 (3.0)
Awareness of current aircraft locations	7.9 (2.1)
Awareness of projected aircraft locations	7.3 (2.8)
Awareness of potential runway incursions	7.9 (2.0)
Awareness of overall traffic situation	7.8 (2.0)

The participants reported that the Integrated EFDI would have a positive effect on ATCT operations. They commented that it was "user friendly" and that it "helped keep the traffic picture at a complex airport." The participants did have some concern about the EFDI being "fat finger" intolerant, or that it would cause too much heads down time. However, these concerns balanced with their appreciation for the Integrated EFDI's ability to consolidate information (especially flight data and aircraft position), to provide accurate data, and to provide positive control.

Perceptual-Spatial EFDI

For the P-S EFDI, the participants had an overall error rate of 7% during the practice and 8% during the test. Table 3 shows the overall (ground and local controller data combined) P-S EFDI interaction data for the test scenarios.

The participants performed 10 of the 17 actions only three times or less on average. Although there was some variability between the participants in the number of actions they performed, the actions they performed most often were FDE selections and FDE repositions. Error rates for these actions were relatively low, and may have improved if we allowed more training time for the participants to familiarize themselves with the touch-sensitive displays. The participants 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%).

Table 3. Interaction Data for the Perceptual-Spatial EFDI

EFDI Action	**Mean (*SD*) Number of Actions**	**Mean (*SD*) Number of Misses**	**Error Rate**
FDE Select	233.25 (28.58)	11.13 (4.36)	5%
FDE Reposition	190.63 (58.17)	14.38 (8.62)	7%
FDE Resequence	3.13 (1.25)	1.13 (1.64)	26%
List Transfer	24.50 (1.00)	0.00 (0.00)	0%
TIPH Clearance	22.00 (4.32)	4.25 (1.26)	16%
Departure Clearance	22.50 (2.38)	2.50 (1.00)	10%
Position Transfer	41.63 (3.70)	2.25 (2.38)	5%
Assign Alt. & Hdg.	0.25 (0.46)	0.00 (0.00)	0%
Assign Altitude	0.63 (0.74)	0.00 (0.00)	0%
Assign Heading	0.25 (0.46)	0.00 (0.00)	0%
Ack. Assignment	1.13 (0.64)	0.00 (0.00)	0%
Ack. Expired Generic Timer	1.13 (0.35)	0.38 (0.52)	25%
Ack. Expired Aircraft Timer	1.25 (0.46)	0.75 (1.39)	38%
Ack. ATIS Update Indicator	33.00 (6.91)	11.75 (10.95)	26%
Ack. Common ATIS Update	2.00 (0.00)	0.13 (0.35)	6%
Assign Runway	0.75 (1.39)	0.00 (0.00)	0%
Assign Intersection	1.00 (0.00)	0.00 (0.00)	0%

Like the Integrated EFDI, the touch-sensitive areas for the expired aircraft timer and ATIS update indicator were too small. The participants performed FDE resequencing and acknowledgment of an expired generic timer very infrequently. Therefore, it is likely that with more practice and use, these actions may become easier to perform. The participants also had relatively high error rates for the Taxi-into-Position-and-Hold (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. Increasing the height of these buttons, along with more time for participants to practice using the touch-sensitive display, may reduce the error rates for TIPH and departure clearance actions. On average, the participants committed 2.5 deselect errors during the 30-min scenarios.

The participants provided subjective ratings of the P-S EFDIs using a 10-point Likert scale (1 = extremely low; 10 = extremely high) for numerous questionnaire items (see Table 4).

Table 4. Post-Scenario Questionnaire Ratings for the P-S EFDI

Questionnaire Item	**Mean (*SD*)**
Effort to use touch-sensitive display	2.6 (1.1)
Effort to maintain flight data	2.4 (0.9)
Readability of text	7.8 (2.6)
Ability to find necessary flight info	8.8 (1.0)
Awareness of current aircraft locations	7.4 (0.8)
Awareness of projected aircraft locations	7.5 (0.9)
Awareness of potential runway incursions	6.5 (2.8)
Awareness of overall traffic situation	7.5 (1.2)

The participants thought that the P-S EFDI would have a positive effect on ATCT operations. They commented that it was “very useful” and that it “reduced coordination and distractions.” The participants did have some concern about the EFDI being “labor intensive” – that some actions may be too difficult – and that it may cause too much “head down” time. However, these concerns traded off with their appreciation for the P-S EFDI’s ability to reduce workload associated with flight data management, to provide accurate data, to organize information, to provide superior memory aids, and to help maintain awareness of the traffic situation.

The participants were able to learn and use each EFDI within the allotted training and practice sessions. However, the participants could have used more time adapting to the touch-sensitive display.

The participants liked both EFDIs and provided a number of comments to improve the existing design. The participants also suggested new features that they thought would be useful, such as a hold short indicator, a closed taxiway or runway indicator, and a runway occupancy indicator.

Recommendations

For both EFDIs, we identified several actions that made the largest contribution to the overall error rate. We recommend the following changes and improvements.

- Increase the size of the touch-sensitive area for the expired generic timer, the aircraft specific timer, and the ATIS update indicator.
- Ensure that the entire FDE frame remains visible at all times on the Integrated EFDI, especially during resequencing.
- Implement the ability to give or take an FDE to or from each controller position.
- Implement the ability to undo actions, such as acknowledging the wrong ATIS update indicator
- Implement a method to provide a gate assignment for an aircraft.
- Implement a method to indicate that a runway or taxi way is closed.
- Implement a method to indicate that an aircraft is on a runway surface on the Integrated EFDI.
- Implement a method to indicate that the controller has given a hold short clearance to an aircraft.

Although the participants learned the EFDI functionality relatively quickly and were able to use it effectively, we recommend longer training times for participants to become accustomed to the touch-sensitive display. Any future usability tests with the EFDIs should incorporate at least an additional 30-60 min of training on use of the touch-sensitive display. The additional training would allow more time for the participants to learn how much pressure is required and how to prevent and correct for errors due to parallax.

Conclusion

Based on the subjective and objective results, the EFDIs should provide an effective and more efficient method for ATCT controllers to manage flight data. Overall, the participants had favorable reactions to both EFDIs, although there were several functions that were difficult to use. We expect to improve the usability of the EFDIs by redesigning some of the elements that participants had difficulty using.

During this usability study, the participant controllers did not have an OTW view, and they had to determine aircraft position either by using the Integrated EFDI, the surface surveillance display, or the short-range radar display. The participants thought that controllers might spend too much time attending to the EFDIs. However, the participants also reported that the EFDIs may increase their awareness of the traffic situation compared to normal operations.

The monitoring task we used for the usability test focused on interface design. The ability to record user interaction with the EFDIs provided useful data to help us refine the design concepts. In subsequent tests, the participants must perform some actions more often to obtain more reliable usability estimates. Future testing should also include simulation pilots for an added level of realism.

Overall, the EFDIs support the controllers' tasks and appear to be a viable alternative to FPSs. In addition to improving current flight data operations, the EFDI concepts may also support future ATCT operations such as staffed virtual towers.

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