An Empirical Evaluation of the Integrated Tower Operations Digital Data System

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Abstract

The Integrated Tower Operations Digital Data System (I-TODDS), designed for use by ground and local control positions in Airport Traffic Control Towers (ATCTs), combines surface surveillance capabilities with electronic flight data management, weather information, digital taxi clearances, and taxiway conformance monitoring. I-TODDS uses a high-resolution touchscreen to simplify flight data management and reduce the controller's need to shift visual attention among disparate sources of information. I-TODDS reduces display clutter by showing only relevant information when needed but still preserving access to the full complement of flight data. Additional tools assist the controller in recording important information, timing operations, providing memory cues, and maintaining awareness of aircraft positions on the surface.

This paper provides a basic description of I-TODDS and presents the results from a recent experiment. The experiment compared I-TODDS to current ATCT operations using paper flight progress strips and surface surveillance in zero-visibility operations. Sixteen current controllers served as participants. The results showed that I-TODDS reduced taxi-out operations by an average of 106 seconds per aircraft and reduced taxi-in operations by 35 seconds per aircraft. I-TODDS also produced an operationally significant reduction in the number and duration of departure delays while increasing the number of departures. Controllers thought that I-TODDS would have a positive effect on their ability to control airport traffic and I-TODDS may be able to support the Staffed NextGen Tower concept. The Federal Aviation Administration currently has a U.S. patent pending for the I-TODDS prototype.

Introduction

The Federal Aviation Administration (FAA) must change the way in which airports and controllers operate to fully realize the benefits of the Next Generation Air Transportation System (NextGen). Two key capabilities discussed in the NextGen concept of operations[1] are Equivalent Visual Operations (EVO) and Network-Enabled Information Access. The Staffed NextGen Tower (SNT) concept, a subcomponent of EVO, purposes to reduce the cost of physical Airport Traffic Control Tower (ATCT) infrastructure with the capability for controllers to manage airport traffic from a remote location. Additionally, the development of electronic flight data (EFD) will enable facilities, air traffic managers, controllers, and automation and decision support systems to access and share all air traffic information related to the National Airspace System (NAS). By replacing the paper flight progress strips (FPSs) that controllers use today, EFD should alleviate some of the human performance constraints inherent in the FPSs. For example, EFD may lower cognitive and physical taskloads associated with flight data management by strengthening the association between an aircraft and its related flight data, thereby increasing controller awareness and reducing flight data management responsibilities. Furthermore, EFD provides the opportunity to integrate flight data with other often-used information sources such as surface surveillance and weather information, thereby reducing the controllers' need to shift visual attention between multiple sources of information.

Interface Development

In anticipation of NextGen and in an effort to improve current ATCT operations, human factors researchers from the FAA Human Factors Team – Atlantic City used a structured process to design and develop I-TODDS. We started by conducting a literature review to understand the tasks of ATCT controllers, to study previous designs for EFD, and to assess state-of-the-art interface design and input techniques[2]. The literature review helped to form the basic design principles that are the foundation of I-TODDS. First, we did not want to replicate the form of the FPS, as this is a historical artifact of flight data management. Second, we wanted the controller to have a direct means of interacting with the interface, so we designed it to accommodate

inputs made by a fingertip (as opposed to a stylus, mouse, or trackball). Finally, we wanted to determine the most efficient method of performing each action and only implement one way to perform each action. This simplified interaction method makes the functions of I-TODDS both easy to learn and to remember. We decided to implement a noun-verb command style so that the controller first selects an object to act upon (noun), and then selects an action to perform (verb). We used the noun-verb command style to reduce errors and increase speed, as well as for simplicity and reversibility[3]. The noun-verb command style reduces errors because commands take effect when the user issues them and the user is focusing attention on the command.

With an established set of design principles, we began the design process based on The Bridge methodology for interface design[4]. We formed a multidisciplinary working group, which included current ATCT controllers, human factors psychologists, and computer software engineers. The working group reviewed an existing task analysis[5] to generate the information requirements for the tasks that controllers most commonly perform in the ATCT at the ground and local control positions. The working group examined the following tasks: (a) performing local situation monitoring, (b) resolving conflict situations, (c) managing air traffic sequences, and (d) routing or planning flights. The working group also reviewed the majority of subtasks within each task. In addition to developing information requirements, the task analysis review identified cognitive bottlenecks and sources of taskload that could be mitigated in the subsequent interface design process.

We then formed an interface design team consisting of ATCT controllers, a human factors psychologist, and a computer software engineer. The interface design team used rapid prototyping techniques and recurrent usability testing to translate the information requirements into an initial interface design. We used paper prototypes, consisting of easel paper and sticky notes, to describe the initial design and to conduct preliminary usability testing. This low-risk, low-cost technique provided a flexible method for us to test and to refine the interface and procedures

before undertaking more expensive and time-consuming software development. The software engineers then used the paper prototypes to guide the software development. The software development used an iterative process that allowed us to conduct informal usability testing throughout the development process. When the initial I-TODDS prototype emerged[6], we conducted formal usability testing with current ATCT controllers serving as participants[7]. During the initial usability test, the controllers monitored an airport traffic scenario and maintained the flight data using the prototype interface. The researchers collected objective usability data and the controllers provided subjective feedback regarding the information and features included in the interface. Although the controllers said they had most of the information they needed for basic operations, the controllers provided suggestions for some additional features, and we noted a number of usability issues. The results of the usability test allowed us to refine the interface, address tasks that had particularly high error rates, and add new features to better accommodate the controllers' tasks[8]. I-TODDS is the resulting prototype.

Interface Description

I-TODDS integrates EFD capabilities, surface surveillance, weather information, wake turbulence indicators, closed runway and taxiway segment indicators, digital taxi clearance, and taxiway conformance monitoring into a high resolution (1200 X 1600 pixels), 21.3″ diagonal resistive touchscreen (see Figures 1 and 2). By integrating information into a single source, I-TODDS should improve controller efficiency by reducing the controllers' cognitive taskload and need to shift visual attention. Integrating EFD with a surface surveillance display associates flight data more closely with aircraft positions instead of requiring controllers to examine FPSs for flight data, shifting their visual attention to the surface surveillance display and out-the-window to verify aircraft position, and then mentally correlating the disparate sources of information. As aircraft move across the airport surface, controllers must maintain the mental connection between the flight data and the aircraft itself. This activity creates cognitive workload and provides the potential for memory lapse or error due to confusion about aircraft

identity and intent. The integration of EFD and surface surveillance reduces the sources of human error and allows the controller to gain both flight data and aircraft position information from a single display that supports their mental representation of the task.

Figure 1. I-TODDS for the ground control position.

Figure 2. I-TODDS for the local control position.

I-TODDS uses color coding to indicate possession information and to alert the controller to important situations. Aircraft that belong to a controller's position appear with a white position symbol, leader line, and data block. Aircraft in a pending state (e.g., waiting on the ramp for taxi), or aircraft that belong to another controller position, appear in gray. I-TODDS monitors the surface surveillance data to notify controllers when an aircraft is moving on or near a runway surface by highlighting the aircraft's data block and Flight

Data Element (FDE) text in yellow. When an aircraft stops on a runway surface, its data block and FDE text appear highlighted in orange. Controllers can also manually activate a generic light-blue highlight to serve as a memory cue for any aircraft. Color coding to indicate possession is preserved during highlighting via the position symbol and leader line.

I-TODDS presents only the information that controllers need, when they need it, in the form of data blocks and the EFD lists, which contain the FDEs. The EFD lists are customized for the ground and local control positions, and the controller can place them on either side of the screen. The ground control position contains EFD lists for pending, outbound, and inbound aircraft. The local control position contains EFD lists for departure and arrival aircraft. We designed each EFD list to provide only the information that the controller needs when they need it. The EFD lists are organized with the newest FDEs at the top of a list, and the oldest FDEs at the bottom of a list. The controller can resequence the FDEs in an EFD list by selecting and dragging an FDE. The resequencing action is animated so that the controller can see the action take place.

The FDEs in the pending list on the ground control position are for aircraft that are waiting to start their initial taxi. FDEs appear in the pending list as aircraft reach their departure ramp spots. A pending FDE contains a data communications indicator, callsign, aircraft type, runway assignment, proposed departure time, and Automatic Terminal Information Service (ATIS) update indicator (see Figure 3). If an aircraft has an Expected Departure Clearance Time (EDCT), then that time is preceded by the letter "E" and is highlighted in the time field of the FDE.

Figure 3. The pending list on the ground control position.

When the ground controller provides an aircraft with a taxi clearance and instructs the pilot to begin the taxi, the controller selects the appropriate pending FDE, and then selects the outbound list header to move the FDE from the pending list to the outbound list. Moving an FDE from the pending list to the outbound list automatically assigns a taxi time and changes the FDE and data block text from gray to white. An outbound FDE contains a data communications indicator, callsign, aircraft type, first departure fix or intersection, assigned runway, assigned taxi time, and ATIS update indicator (see Figure 4). When the ground controller instructs the pilot to contact the tower (i.e., local controller), the controller selects the aircraft's FDE, or data block, and then selects the Local button at the bottom of the outbound list to transfer the flight data to the local controller.

Figure 4. The outbound list on the ground control position.

The inbound list on the ground control position contains FDEs for arrival aircraft. Arrival FDEs on the ground control position contain a callsign and aircraft type (see Figure 5). When the ground controller instructs the pilot to contact ramp control, the controller selects the aircraft's FDE, or data block, and then selects the Ramp button below the arrival list to transfer the flight data to the ramp controller.

Figure 5. The inbound list on the ground control position.

The departure list on the local control position contains FDEs for aircraft that are ready to depart. The departure FDEs show a data communications

indicator, callsign, aircraft type, first departure fix or intersection, runway assignment, and assigned taxi time (see Figure 6). The FDEs in the departure list are sorted by runway assignment. FDEs for aircraft that are departing from different runways are separated by a blue line. When the surface surveillance system detects that an aircraft has started its takeoff roll, the assigned taxi time on the FDE is replaced with a departure spacing timer. The departure spacing timer counts up in 1-second increments to help the local controller decide when to depart the next aircraft from the same runway. The departure spacing timer also appears next to the appropriate runway, so that it is visible even after the FDE is transferred to another controller position. When the local controller instructs the pilot to contact the departure controller, the controller selects the aircraft's FDE, or data block, and then selects the Departure button to transfer the flight data to the departure controller.

Figure 6. The departure list on the local control position.

FDEs appear in the arrival list on the local control position when aircraft are at or near the outer marker (approximately 5 nm from the runway). Theoretically, the arrival FDEs would be transferred from the terminal arrival controller to the local controller. The arrival FDEs on the local control position contain a callsign, aircraft type, and runway assignment (see Figure 7). When an aircraft

lands and the local controller instructs the pilot to contact ground control, the controller selects the aircraft's FDE, or data block, and then selects the Ground button at the bottom of the inbound list to transfer the flight data to the ground control position's inbound list.

Figure 7. The arrival list on the local control position.

Like the FDEs, data blocks provide only the information that controllers need for a particular operation. Figure 8 shows an arrival data block that contains only the callsign and aircraft type with the associated position symbol and leader line. Figure 9 shows a departure data block that contains the callsign, departure fix, aircraft type, and runway assignment, along with the associated position symbol, leader line, hold short indicator (dashed vertical line), and acknowledged data communications indictor (circle).

Figure 8. Arrival data block.

Figure 9. Departure data block.

Selecting an aircraft's FDE highlights the data block, and vice-versa (see Figure 10). When the controller selects an aircraft's data block, or FDE, the readout area (located above the EFD list)

displays the complete set of flight data for the associated aircraft, including the callsign, aircraft type, data communications indicator, computer identification number, beacon code, proposed departure time, assigned taxi time, expected departure clearance time, assigned heading, assigned altitude, assigned runway, and route of flight (see Figure 11). The readout area also displays additional information such as digital communications requests and clearances, and missed approach indicators.

Figure 10. A selected FDE and associated data block.

Figure 11. The readout area.

I-TODDS provides basic weather information in a movable box (located in the upper-right corner of Figures 1 and 2). The weather information includes the current ATIS code, wind direction, wind speed and gust, altimeter reading, and runway visual range for the active runways at their touchdown, midpoint, and rollout areas (see Figure 12). The ATIS code flashes whenever it updates, and an ATIS update indicator appears on the right side of each FDE to remind the controller to ensure that each pilot has the current ATIS information. The FDE ATIS update indicator appears as a box on the right side of an FDE. After providing the pilot with the current ATIS information, the controller can touch the ATIS update indicator on each FDE to make it disappear.

Figure 12. The weather information area.

The controller can also issue canned digital taxi clearances through I-TODDS. When an aircraft is ready to taxi, the pilot makes a request for a taxi clearance either by voice or by data communications. If the pilot makes the request via data communications, I-TODDS notifies the controller via the data communications indicator in the aircraft's FDE and data block. The controller can select the aircraft's FDE or data block and read the request in the readout area, and then provide a digital taxi clearance, including hold short instructions, by selecting the D-Taxi button. I-TODDS notifies the controller if the data communication message failed or timed out. When a pilot has accepted and acknowledged a digital taxi clearance, I-TODDS monitors the aircraft for taxiway movement conformance and alerts the controller if the pilot deviates from the assigned clearance by flashing the aircraft's FDE and data block in red.

I-TODDS also allows for flight data amendments and contains a number of quick-action buttons that can be used to set timers, assign a new runway or intersection departure, or mark a hold short clearance. For more detailed information about I-TODDS, a complete description is contained in FAA technical papers,[5,7] which are available online at http://hf.tc.faa.gov, or by contacting the author.

Empirical Testing and Results

We conducted a high-fidelity, human-in-the-loop experiment to compare I-TODDS to current ATCT operations during zero-visibility conditions. The experiment addressed three primary questions regarding I-TODDS: Does I-TODDS provide an

advantage compared to FPSs with surface surveillance in zero-visibility conditions? Could I-TODDS support SNT operations? Did the most recent design changes improve the overall usability of I-TODDS?

Sixteen current controllers from Las Vegas, Miami, Philadelphia, Phoenix, and Salt Lake City ATCTs participated in groups of two. The participants had a mean age of 42.4 years. The participants had worked in an ATCT for an average of 17.8 years. After receiving touchscreen and I-TODDS training, the participants worked under the experimental conditions. The results presented in this paper focus on the two conditions that include surface surveillance: I-TODDS and FPSs with surface surveillance.[*] A paper describing the complete set of results is in preparation[9].

After the initial training, the participants completed eight practice scenarios and eight test scenarios. Each scenario lasted 40 minutes and the participants worked half of the scenarios from the ground control position and half of the scenarios from the local control position. The traffic scenario was based on Boston Logan International Airport (BOS), using a 27/33 runway configuration, but did not replicate the BOS airport in its entirety. The traffic scenario simulated a very heavy traffic volume (49 departures and 31 arrivals) with aircraft arriving and departing on all three runways (27, 33L, and 33R). The experimental design counterbalanced the order of conditions and controller positions across the eight groups of participants. The experimenters collected objective data including airport system metrics and I-TODDS usability, and subjective measures including the participants' assessments of workload, awareness, and I-TODDS usability.

Compared to FPSs with surface surveillance, I-TODDS decreased the duration of taxi-out operations by an average of 106 seconds and reduced the duration of taxi-in operations by an average of 35 seconds. The participants' use of I-TODDS also resulted in an operational increase in the number of departures and a reduction in the

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[*]The experiment examined a total of four different conditions: I-TODDS, FPSs with surface surveillance, Perceptual-Spatial TODDS (i.e., TODDS without surface surveillance), and FPSs without surface surveillance.

number and duration of departure delays – but these differences were not statistically significant. In the I-TODDS condition, the participants were able to depart two additional aircraft during the 40-minute scenario, the number of departure delays were reduced from 6.6 to 5.3, and the duration of departure delays was reduced by an average of 43 seconds. When the participants used I-TODDS, ramp-waiting time increased by an average of 25 seconds – primarily due to the delay associated with data communications. However, data communications decreased the number of ground controller-to-pilot transmissions from 157 to 135, and reduced the duration of those transmissions from 4.5 to 3.5 seconds.

The overall error rate for I-TODDS decreased from 12% in the original design concept to 4%. The participants reported that I-TODDS would be useful and thought it would have a positive effect on ATCT operations. Because the participants did not have an out-the-window view, the results of this experiment suggest that I-TODDS may be able to support SNT operations.

Conclusion

The results of the experiment suggest that I-TODDS may be able to support the SNT concept. The participants were able to control complex, high taskload airport traffic without an out-the-window view at an unfamiliar airport using an unfamiliar system. The experimental conditions were extreme and pushed the controllers and the I-TODDS system to their limits. Nevertheless, the controllers were able to perform their tasks just as well, or better, with I-TODDS compared to using the current system of FPSs and surface surveillance. Integrating the necessary information into a single display and providing new tools reduced the controllers need to shift their visual attention, and resulted in an improvement in airport efficiency.

Future experiments should focus on new and expanded capabilities such as data communications and how I-TODDS may enable the SNT concept. In particular, researchers should examine how much time controllers spend looking at I-TODDS vs. looking outside the tower. Researchers must understand how "heads-down time" may affect

controllers and determine the value of allocating visual attention between the various sources of information in the ATCT environment. Future experiments should examine I-TODDS with and without an out-the-window view to assess its ability to support both current and future ATCT operations. Researchers must examine what information ATCT controllers glean from looking out the window and determine how, or if, that information can be replaced using an interface such as I-TODDS. When controllers do not have an out-the-window view and lose access to vital information (e.g., zero-visibility or SNT operations), researchers must determine what

constraints, if any, this imposes upon controllers, airport efficiency, and safety.

Researchers should also continue to expand the scope of I-TODDS to accommodate more tasks and to improve its overall usability. We recommend that future experiments provide more training time on I-TODDS to increase the participants' overall familiarity with the system. Increasing the participants' familiarity with I-TODDS should improve their ability to use the system and result in better overall performance and airport efficiency.

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