HIGH-FIDELITY SIMULATION TO COMPARE THE TOWER OPERATIONS DIGITAL DATA SYSTEM TO FLIGHT PROGRESS STRIPS

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The current experiment used a high-fidelity, human-in-the-loop simulation to compare the Tower Operations Digital Data System (TODDS) to paper Flight Progress Strips (FPSs) during zerovisibility Airport Traffic Control Tower operations. Sixteen current controllers participated in groups of two. Each group received touchscreen and TODDS training before completing eight practice and eight test scenarios. The participants worked at both the ground and local control positions under four experimental conditions. The participants used one of four systems – the Integrated TODDS, FPSs with Airport Surface Detection Equipment – Model X, Perceptual-Spatial TODDS, or FPSs only – to control airport traffic. The participants had a Standard Terminal Automation Radar System display in all conditions, but did not have an out-the-window view. Dependent measures included the number and duration of airport operations, the number and duration of communications, TODDS usability, and participant opinion. We found advantages for surface surveillance and TODDS, and Integrated TODDS provided additional benefits.

Airports are central to implementing the Next Generation Air Transportation System (NextGen), and the Federal Aviation Administration (FAA) must change the way in which airports operate to fully realize its benefits. Two key capabilities discussed in the NextGen concept of operations (Joint Planning and Development Office, 2007) are Equivalent Visual Operations (EVO) and Network-Enabled Information Access. A subcomponent of EVO, the Staffed NextGen Tower (SNT) concept, proposes to reduce the cost of physical Airport Traffic Control Tower (ATCT) infrastructure with the ability to manage airport traffic from a remote location. The development of Electronic Flight Data (EFD) will take advantage of network-enabled information access, which allows stakeholders to access and share all air traffic information related to the National Airspace System. The implementation of EFD may also alleviate some of the human performance constraints inherent in the current paper Flight Progress Strips (FPSs). For example, EFD can reduce the controllers' need to search for information presented in visually separate locations and provide the opportunity to integrate flight data with other often-used information sources, such as surface surveillance and weather information.

To address the role of EFD, Engineering Research Psychologists from the FAA Human Factors Team – Atlantic City designed two prototype Electronic Flight Data Interfaces (EFDIs) for use in ATCTs (see Truitt, 2006a, 2006b). The Integrated EFDI combined EFD with a surface surveillance capability. The Perceptual-Spatial EFDI provided a way for controllers to spatially organize EFD using a surface map of an airport without surface surveillance. We have recently refined the concepts to create the Tower Operations Digital Data System (TODDS), as described by Truitt (2008). To design the Integrated TODDS (I-TODDS) and the Perceptual-Spatial TODDS (PS-TODDS), we used a process based on "The Bridge" methodology (Dayton, McFarland, & Kramer, 1998) that relies in part on usability testing throughout the development process. By examining task flows and paper prototypes, we were able to ensure that the resulting interfaces would function as expected, and we could address numerous problems before the software development began. We continued the usability testing during software development. Once the initial prototypes were functional, we conducted formal usability testing (Truitt & Muldoon, 2007).

We refined the newest version of TODDS to address the results of the usability test and to expand the scope of the interfaces beyond flight data management. In addition to making the most difficult features easier to use, we added the ability to issue digital taxi-out clearances, perform taxi conformance monitoring, indicate closed runway and taxiway segments, and access integrated weather information, including advisories for wake turbulence separation. We also designed a touchscreen training protocol to better familiarize users with the interface hardware. We conducted the current experiment to evaluate TODDS against comparable conditions using FPSs.

Method

We conducted the experiment in the Research, Development, and Human Factors Laboratory at the FAA William J. Hughes Technical Center. The experiment placed current ATCT controllers in a high-fidelity simulation to compare TODDS to FPSs under zero-visibility conditions (i.e., no out-the-window view). The experiment used a

2 (run number – first vs. second) X 2 (flight data type – TODDS vs. FPS) X 2 (surface surveillance – yes vs. no) repeated measures design.

Participants

We recruited 16 current ATCT controllers from busier (level 10 and above) facilities and received volunteers from Phoenix, Las Vegas, Miami, Philadelphia, and Salt Lake City ATCTs. The participants had a mean age of 42.4 years and had actively worked in an ATCT for an average of 17.8 years.

Apparatus

We used three 21.3" 1,600 x 1,200 pixel touchscreen displays: Two contained the TODDS ground and local control positions, and one contained the Airport Surface Detection Equipment-Model – X (ASDE-X) (no touchscreen capabilities). A fourth display presented Standard Terminal Automation Replacement System (STARS) data on a 20" Tower Display Workstation. A fifth display showed a screen of the Information Display System (IDS), including the current Automatic Terminal Information Service (ATIS) code, wind direction, speed, gust, and runway visual range. We constructed two FPS bays that fit over the touchscreens for use in the appropriate experimental conditions.

Procedure

The participants arrived and worked in groups of two. Before the experiment, they signed an Informed Consent Statement, completed a Biographical Questionnaire, and received a briefing on the simulated airport operations. The participants then completed the touchscreen and TODDS training protocol.

The touchscreen training protocol consisted of three specific tasks (select a single button, select two buttons in sequence, and drag a button to a target area), with 10 different button sizes across multiple trials. The button sizes ranged from 1.5 X 1.5 in. (3.8 X 3.8 cm) to 0.4 X 0.4 in. (1.1 X 1.1 cm). The buttons and target zone in the drag task appeared at random locations on the touchscreen. After completing all three tasks to criteria for a button size, the participants repeated the tasks with the next button size. The entire touchscreen training protocol lasted about 2 hr. The participants then received training on TODDS using a structured protocol. Half of the groups received training on I-TODDS first, whereas the other half received training on P-S TODDS first. The TODDS training lasted about 2 hrs.

After training, the participants completed eight practice and eight test scenarios. In the I-TODDS condition, the participants had an ASDE-X display that was integrated with EFD, weather information, digital taxi clearances, and taxi conformance monitoring on a single display. In the FPS + ASDE-X condition, the participants had FPSs, ASDE-X, and IDS. In the P-S TODDS condition, participants used EFD integrated with weather information and digital taxi clearance, but ASDE-X was unavailable. In the FPS-only condition, the participants used FPSs and the IDS, but ASDE-X was unavailable. The participants had a STARS display in all conditions. The participants worked two consecutive scenarios in each condition, alternating between the ground and local control positions. The participants controlled the airport traffic and maintained flight data for each aircraft. They did not have an out-the-window view, but they could assess aircraft position from pilot reports, STARS, and surface surveillance (if available). We counterbalanced the order of conditions. The participants completed the Post-Scenario Questionnaire (PSQ) at the end of each test scenario and completed the Post-Experiment Questionnaire after completing all scenarios.

Subject matter experts developed one 40-min airport traffic scenario based on Boston Logan International Airport using runways 27, 33L, and 33R as the active runways. The scenario included 49 departures and 31 arrivals, with arrivals and departures on all three runways. There were a variety of aircraft types, including civil and commercial aircraft, all of which were capable of data communications. We then created 16 different "versions" of the base scenario by changing only the aircraft call signs to reduce the potential effects of traffic demand and aircraft type while preventing the participants from recognizing that each scenario was identical. We presented each version of the scenario in the same order for all participants, although the participants experienced them in a different combination of experimental conditions. The scenario began with aircraft already on the airport surface and in the air. Five simulation pilots communicated with the participants and entered commands to move aircraft through the scenarios.

Results

We analyzed the data using the appropriate repeated measures analysis of variance (ANOVA) for each dataset and Tukey's Honestly Significant Difference (HSD) post hoc test, as needed. All statistically significant results used the criteria of $p \le .05$.

Number of operations. The mean number of arrivals did not differ between conditions. However, the participants were able to depart approximately 50% more aircraft when surface surveillance was available, F(1, 7) = 114.94. There was no difference in the number of missed approaches (see Table 1).

| | Arrivals | Departures | Missed Approaches |
|--------------|------------|------------|----------------------|
| I-TODDS | 29.2 (0.9) | 33.8 (6.8) | 0.9 (1.1) |
| FPS + ASDE-X | 29.3 (0.9) | 31.8 (6.6) | 0.8 (1.1) |
| P-S TODDS | 29.2 (1.3) | 20.5 (7.0) | 0.8 (1.3) |
| FPS | 29.3 (0.8) | 20.3 (3.8) | 0.7 (0.8) |

Table 1. Mean (SD) Number of Airport Operations by Type and Condition.

Ramp waiting time. We recorded the time that each departure aircraft reached a ramp spot and the time of each aircraft's first taxi movement. Using these times, we calculated a mean ramp waiting time. There was a main effect of surface surveillance presence, F(1, 7) = 54.77, and flight data type, F(1, 7) = 17.35 (see Figure 1). When surface surveillance was unavailable, aircraft waited on the ramp about 80 s longer than when surface surveillance was available. The ramp waiting time was about 37 s longer when the participants used TODDS instead of FPSs. Once a departure aircraft reached a ramp spot in the TODDS conditions, the pilot requested a taxi clearance via data communications. The ground controller then issued a digital taxi clearance via TODDS. It took as long as 30 s for a digital taxi clearance to reach an aircraft and for the pilot to accept the clearance. The ground controller then instructed the aircraft via voice communications to begin taxiing. The process of sending, receiving, and acknowledging digital taxi clearances took a significant amount of time due to data transmission.

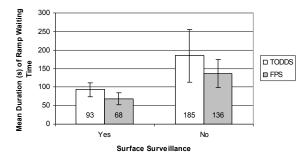


Figure 1. Mean duration (s) of ramp waiting time by surface surveillance presence and flight data type.

Taxi operations. For taxi-out operations, we recorded the duration from when an aircraft made its first taxi movement until departure (i.e., wheels up), and we found a significant interaction of surface surveillance presence and flight data type, F(1, 7) = 6.68. A planned comparison confirmed that aircraft took significantly less time to taxi out (106 s on average) when the participants used I-TODDS compared to FPS + ASDE-X, F(1, 7) = 6.35. For taxi-in operations, we recorded the duration from when an aircraft landed until it reached an arrival ramp spot, and we found a significant main effect of surface surveillance presence, F(1, 7) = 44.52. Taxi-in operations were over 1 min shorter when the participants had surface surveillance. A planned comparison showed that taxi-in operations were significantly shorter (35 s on average) in the I-TODDS condition than in the FPS + ASDE-X condition, F(1, 7) = 10.79 (see Figure 2). Neither taxi-out nor taxi-in times were significantly different when surface surveillance was unavailable.

Departure delays. We counted a departure delay when the time between an aircraft's first taxi movement and departure exceeded 20 min. There was a significant main effect of surface surveillance presence on the number of departure delays, F(1, 7) = 14.74. There were 2.5 fewer delays when surface surveillance was present. Departure delays were significantly shorter by 202 s when surface surveillance was present, F(1, 7) = 25.91. There were 1.2 fewer delays and those delays were 43 s shorter in the I-TODDS condition compared to the FPS + ASDE-X condition, but these differences were not statistically significant (see Figure 3).

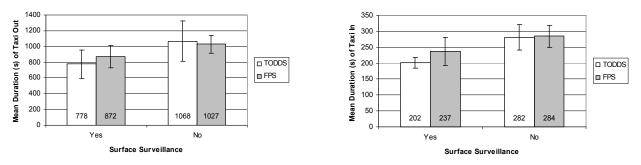


Figure 2. Mean duration(s) of taxi-out (left) and taxi-in (right) operations by surface surveillance presence and flight data type.

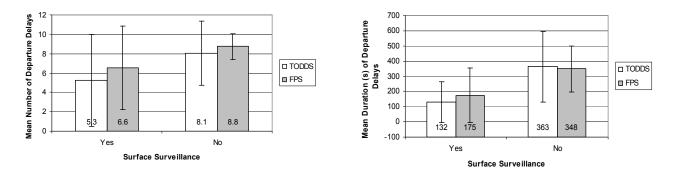


Figure 3. Mean number (left) and duration (right) of departure delays by surface surveillance presence and flight data type.

Radio transmissions. The participants made two fewer transmissions per minute when surface surveillance was present, F(1, 7) = 38.96. The participants also made two fewer transmissions per minute when using TODDS compared to using FPSs, F(1, 7) = 17.93. When using TODDS, the participants' transmissions from the ground controller position were significantly shorter, F(1, 7) = 79.02. When using FPSs, the participants had to give a full taxi clearance for departures (e.g., "United one niner, taxi to runway two seven via alpha and echo, hold short runway three three left."). In contrast, once the pilot had acknowledged a digital taxi clearance issued via TODDS, the participants only had to tell the pilot to "resume taxi" to start an aircraft's ground movement (see Figure 4).

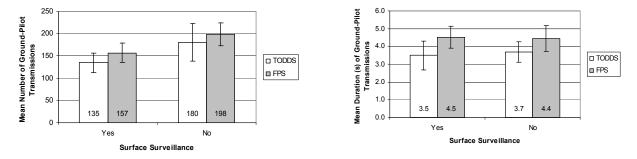


Figure 4. Mean number (left) and duration (s) (right) of ground controller to pilot transmissions by surface surveillance presence and flight data type.

Usability - Integrated TODDS. We calculated an error rate (ER) percentage for each TODDS action type by dividing the number of successful actions (S) by the sum of successful actions (S) and failed actions (F), and then multiplying the result by 100, so that $ER\% = S/(S + F) \times 100$.

There were 29 distinct actions that the participants could perform with I-TODDS. Of these actions, they performed 18 of them at least once on average. There was substantial variability between the participants in how often they performed each action. With the exception of Flight Data Element (FDE) selects at the local control position, the error rate for the most commonly performed actions decreased compared to the initial usability study (Truitt & Muldoon, 2007). The overall error rates (calculated over all actions, regardless of frequency) decreased from 11% to 4% at the ground control position and from 13% to 4% at the local control position (see Table 2).

| | Ground | | | Local | | |
|--------------------|-----------------------------------|---------------------------|-------------|-----------------------------------|---------------------------|-------------|
| Touchscreen Action | Mean (SD) Number of Actions | Mean Error Rate (%) | % Change | Mean (SD) Number of Actions | Mean Error Rate (%) | % Change |
| Data Block Select | 158.8 (73.19) | 1 | -3 | 108.3 (63.29) | 3 | -4 |
| FDE Select | 35.1 (45.35) | 5 | -8 | 18.4 (21.61) | 10 | +4 |
| Reposition | 45.2 (3.31) | 4 | -4 | 62.3 (49.96) | 5 | -9 |
| List Transfer | 36.4 (2.19) | 4 | -2 | NA | NA | NA |
| Position Transfer | 39.1 (4.11) | 2 | -4 | 29.4 (2.28) | 4 | -10 |
| External Transfer | 28.6 (1.93) | 4 | -2 | 31.9 (6.23) | 3 | -11 |
| ATIS Update Ack. | 2.4 (5.27) | 25 | -28 | 1.6 (5.21) | 0 | -35 |
| D-Taxi | 40.4 (3.67) | 6 | NA | NA | NA | NA |
| Total Actions | 389.2 (99.44) | 4 | -7 | 253.2 (101.64) | 4 | -9 |

 Table 2. Mean (SD) Number of Touchscreen Actions, Error Rates, and Percentage Change in Error Rates from the Initial Usability Study for the Ground and Local Control Positions with Integrated TODDS.

Usability – Perceptual-Spatial TODDS. There were 27 distinct actions that the participants could perform on PS-TODDS. Of these actions, they performed 11 of them at least once on average. There was substantial variability between the participants in how often they performed each action. With the exception of FDE repositions, the error rates for the most commonly performed actions decreased compared to the initial usability study (Truitt & Muldoon, 2007). The overall error rate decreased from 7% to 4% at the ground control position and decreased from 9% to 4% at the local control position. The participants performed the Taxi-into-Position-and-Hold (TIPH) clearance at the local control position with a lower error rate because we locked the TIPH buttons in place so that the participants could not move (i.e., drag) them when selected (see Table 3).

We attribute the overall reduction in error rates primarily to the touchscreen training protocol and to a slight increase in familiarity with the TODDS interfaces prior to data collection. The dramatic reduction in the error rate for FDE ATIS update acknowledgments was due to a redesign of the touch sensitive area for this particular element. Compared to the initial usability study, the participants made more touchscreen actions, with fewer errors, in the current experiment.

| | Ground | | | Local | | |
|--------------------|--------------------------------|---------------------------|-------------|-----------------------------------|---------------------------|-------------|
| Touchscreen Action | Mean (SD) Number of Actions | Mean Error Rate (%) | % Change | Mean (SD) Number of Actions | Mean Error Rate (%) | % Change |
| FDE Select | 278.4 (67.99) | 2 | -3 | 209.6 (54.05) | 4 | 0 |
| FDE Reposition | 154.5 (49.07) | 9 | +1 | 93.6 (41.97) | 7 | +2 |
| FDE Resequence | 0.1 (0.34) | 0 | -18 | 1.1 (1.48) | 0 | -5 |
| Position Transfer | 23.3 (5.42) | 3 | -2 | 28.9 (1.65) | 2 | -3 |
| External Transfer | 27.1 (2.28) | 1 | -4 | 20.8 (4.93) | 1 | -4 |
| FDE Recall | 1.2 (1.42) | 13 | NA | 0.0 (0.00) | 0 | NA |
| TIPH | NA | NA | NA | 34.8 (9.63) | 1 | -15 |
| Depart. Clearance | NA | NA | NA | 20.8 (5.71) | 3 | -7 |
| Highlight | 0.3 (0.87) | 0 | NA | 2.8 (7.47) | 0 | NA |
| ATIS Update Ack. | 8.4 (10.85) | 3 | -11 | 5.9 (7.20) | 2 | -34 |
| D-Taxi | 29.9 (5.66) | 3 | NA | NA | NA | NA |
| Total Actions | 524.9 (119.78) | 4 | -3 | 418.6 (103.84) | 4 | -5 |

 Table 3. Mean (SD) Number of Touchscreen Actions, Error Rates, and Percentage Change in Error Rates from the Initial Usability Study for the Ground and Local Control Positions with Perceptual-Spatial TODDS.

 Post-scenario questionnaire. Overall, the presence of surface surveillance had the largest effect on the PSQ ratings. With surface surveillance, the participants reported that they needed less effort to maintain flight data and issue taxi clearances; they were better able to detect aircraft on a runway; they were more aware of projected aircraft positions; they had a greater awareness of potential runway incursions; they were more aware of the overall traffic situation; and they had lower workload due to controller-pilot communications. Also, when working at the ground control position with surface surveillance, the participants reported that they were better able to find flight information. At the local control position they were better able to find weather information and had a better awareness of the current location of aircraft when surface surveillance was available.

When the participants used TODDS, they thought that it was easier to issue taxi clearances from both the ground and local control positions. When they worked at the local control position with TODDS, they reported a greater awareness for potential runway incursions. When working at the ground control position with TODDS, the participants reported lower workload due to controller-pilot communications. The participants rated their awareness for current aircraft position as being low at the ground control position in the FPS-only condition, but rated it even lower in the PS-TODDS condition. The participants rated their awareness of current aircraft locations equally high when surface surveillance was available, regardless of the flight data type.

Post-experimental questionnaire. The participants reported that the elements of the readout area, weather information, and FDEs of TODDS were readable. They also gave high ratings for the readability of data blocks in the I-TODDS. The participants rated the effort to use the touchscreen in I-TODDS as moderate, whereas the PS-TODDS took a little more effort, perhaps because they had to move each FDE multiple times. The participants thought that the I-TODDS would have a moderately positive effect on their ability to control airport traffic, but PS-TODDS would have only a slightly positive effect.

Conclusion

The presence of surface surveillance significantly improved airport efficiency by increasing the controllers' awareness of the traffic situation and the number of departures; and by reducing ramp waiting time, number and duration of departure delays, number of ground controller-to-pilot transmissions, and controller effort. TODDS increased ramp waiting time, but decreased the number and duration of ground controller-to-pilot transmissions. I-TODDS decreased the duration of taxi-out and taxi-in operations. I-TODDS also provided an operational increase in the number of departures and a reduction in the number and duration of departure delays, but these differences were not statistically significant. The overall error rate for TODDS usage was 4% – a reduction from the initial design concept. The participants found TODDS useful and thought it would have a positive effect on ATCT operations, especially when integrated with surface surveillance, as with I-TODDS. However, they had some reservations about PS-TODDS because it required more effort and could mislead the ground controller regarding aircraft position. Based on the results of this experiment, I-TODDS may be able to support SNT operations as an alternative to an out-the-window view.

References

- 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*. CRC Press.
- Joint Planning and Development Office. (2007). Concept of operations for the next generation air transportation system (Version 2.0). Retrieved January 8, 2009 from http://www.jpdo.gov/library/NextGen_v2.0.pdf.
- Truitt, T. R. (2006a). *Electronic flight data in airport traffic control towers: Literature review* (DOT/FAA/CT-05/13). Atlantic City International Airport, NJ: FAA William J. Hughes Technical Center.
- Truitt, T. R. (2006b). Concept development and design description of electronic flight data interfaces for airport traffic control towers (DOT/FAA/CT-06/17). Atlantic City International Airport, NJ: FAA William J. Hughes Technical Center.
- Truitt, T. R. (2008). Concept development and design description of the tower operations digital data system (DOT/FAA/TC-TN08/09). Atlantic City International Airport, NJ: FAA William J. Hughes Technical Center.
- Truitt, T. R., & Muldoon, R. V. (2007). New electronic flight data interface designs for airport traffic control towers: Initial usability test (DOT/FAA/TC-07/16). Atlantic City International Airport, NJ: FAA William J. Hughes Technical Center.