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Data Communications Segment 2 Airport Traffic Control Tower Human-in-the-Loop Simulation

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16. Abstract

This technical report provides a brief literature review of previous research on air traffic control concepts relevant to the Data Communications (Data Comm) program and examines the use of digital-taxi (D-Taxi) clearances for departure aircraft under three levels of data link equipage (Voice Only vs. 40% Data Comm vs. 75% Data Comm). Sixteen current controllers participated in a high-fidelity, human-in-the-loop simulation to assess the potential effects of D-Taxi on controller communications, workload, and performance. We collected measures of airport system efficiency and usability measures for the Tower Operations Digital Data System that enabled the D-Taxi functions and taxiway conformance monitoring. We examined the specific effects of taxi conformance monitoring and a complete data link system failure in an additional exploratory scenario. This report provides a detailed set of results and recommendations for future research and requirements generation that the Federal Aviation Administration should consider when implementing the Data Comm Segment 2 concepts.

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Executive Summary

In today's Air Traffic Control system, when a pilot is ready to taxi out for departure, the pilot must call the ground controller in the Airport Traffic Control Tower (ATCT) via voice radio communications and request a taxi clearance to the runway. The ground controller responds to the pilot's request by providing a detailed taxi route and verifying that the pilot has obtained the most recent airport and weather information. The pilot then reads the taxi clearance back to the ground controller, who must listen carefully to ensure that the pilot repeated the information correctly. If the pilot's readback is incorrect, the ground controller must correct any misunderstandings regarding the clearance and then, once again, verify the pilot's readback. This process of verbal communication between the ground controller and pilot takes time, contributes to congestion of the voice radio frequency, and presents the potential for errors due to inaccurate pilot readbacks and the failure of the ground controller to correct any misunderstandings (i.e., controller hearback error).

The Data Communications (Data Comm) Segment 2 program addresses the current problems associated with verbal communications by implementing digital-taxi (D-Taxi) clearances during the 2017-2022 timeframe. D-Taxi will allow pilots and controllers to communicate via digital messaging to reduce voice radio frequency congestion and to reduce the potential for readback and hearback errors. D-Taxi clearances and related information can easily be shared across the National Airspace System (NAS) and will inform other decision support systems of the pilot's intentions. D-Taxi clearances also enable taxiway conformance monitoring that will detect when a pilot deviates from the assigned taxi route and then alert the controller of the deviation.

The current experiment examines the effects of D-Taxi when either 40% or 75% of the departure aircraft are data link equipped and compares these conditions to voice only operations. We designed the experiment to determine whether the controllers' use of D-Taxi affected voice communications, controller workload, controller awareness of airport traffic, time required to execute surface operations, or airport arrival and departure rates. We also wanted to know if the D-Taxi indicators that we designed were adequate and if the D-Taxi functions were easy to use. The experiment included additional scenarios outside of the main experimental design to determine whether controllers were able to notice Data Comm service failures and to see how they reacted to those failures.

Sixteen current controllers from Level 10 and above ATCT facilities participated in groups of two. Each group worked in the Research, Development, and Human Factors Laboratory over the course of three days. They used the Tower Operations Digital Data System (TODDS) at one ground control and one local control position to control busy airport traffic at an airport, similar to Boston Logan International Airport, using a 27/33 runway configuration. The participants completed a touchscreen training protocol, TODDS training, and practice scenarios prior to working in the three experimental conditions. The participants worked at both the ground and local control positions in each of the experimental conditions and provided online ratings of subjective workload. The participants also worked in two exploratory scenarios that contained a complete data link failure and recovery and aircraft that failed to conform to their taxi clearances. The participants completed questionnaires after each scenario and at the end of the experiment.

D-Taxi clearances for departure aircraft reduced the usage of the ground control voice radio frequency by 12.5%, when 75% of the aircraft were data link equipped, without increasing workload or heads-down time. The participants preferred issuing taxi clearances via D-Taxi compared to issuing taxi clearances via voice because it reduced their communication responsibilities and removed the potential for readback and hearback errors. D-Taxi did not adversely affect the overall surface operations, the arrival and departure rates, or the number and duration of delays. Although aircraft waited on the ramp longer when they received a D-Taxi clearance (due to the technical and pilot response delays associated with data link communications), better aircraft metering and less taxiway congestion mitigated the ramp delays and resulted in equivalent taxi-out operations. The participants provided a number of suggestions for improving D-Taxi and the overall design of TODDS.

Future research should be founded on an agreed upon set of Data Comm procedures and should incorporate other potential data link functions and planned future systems, such as decision support tools, that may interact with D-Taxi operations. Researchers should build upon the human-in-the-loop simulation capabilities and should examine more complex and all-encompassing operations, such as air-ground integration and push back from the gate or ramp control. We recommend that the Federal Aviation Administration continue to research and develop Data Comm concepts for implementation during the Segment 2 timeframe.

1. INTRODUCTION

The air traffic controllers in Federal Aviation Administration (FAA) Airport Traffic Control Towers (ATCTs) manage the aircraft moving on the airport surface as well as airborne aircraft that are arriving or departing the airport. There are a number of control positions in the ATCT, including ground control, local control, flight data, and clearance delivery. The ground controller typically handles aircraft and vehicles on the surface movement area. The ground controller establishes a sequence for the departures and provides taxi clearances to maintain efficient use of the runways and a smooth flow of aircraft to and from the ramp. The local controller provides takeoff and landing clearances. Both controller positions may be responsible for clearing aircraft across active runways, and sometimes they may need to coordinate with each other to accomplish this task. Currently, ATCT controllers issue all clearances to pilots via radio voice communications except for predeparture clearances, which occur before the aircraft *pushes back* from the gate. The flight data/clearance delivery position in the ATCT may issue predeparture clearances via data link – a digital information transfer system for non-time-critical events between controllers and the flight decks of properly equipped aircraft. ATCT controllers currently issue amendments to these initial data link clearances via radio voice transmissions; however, studies have suggested that in the future controllers could make clearance amendments via data link (FAA, 2008; George Mason University [GMU], 2008b) and use data link to issue additional complex clearances (GMU, 2008a).

The FAA has identified Data Communications (Data Comm) as an enabling technology for Next Generation Air Transportation System (NextGen) operations, such as Trajectory-Based Operations (TBOs), to safely, strategically, and efficiently manage aircraft on the airport surface (Joint Planning Development Office, 2007). In particular, the FAA proposes that ATCT controllers use Data Comm for digital-taxi (D-Taxi) clearances. In the future, ATCT controllers may use D-Taxi clearances for both taxi-out and taxi-in operations. D-Taxi clearances for taxi-out operations may include information such as current Automatic Terminal Information System (ATIS) information or Data Link Operational Terminal Information System (D-OTIS) information, detailed taxi route instructions, and "hold short" instructions. D-Taxi clearances for taxi-in operations may include preferred taxiway information and gate assignments. Controllers would not use D-Taxi for time-critical events such as clearances to begin taxi movements, to transfer control, or to cross runways. Fundamental to enabling an effective Data Comm system will be the controllers' ability to manage exchanged messages (e.g., taxi-out instructions), using effective display designs and supporting automation capabilities (e.g., conformance monitoring) in a mixed equipage environment. ATCT and airport surface operations may benefit as a result of the interaction between Data Comm and automated decision support tools, including the following results.

- Increased safety in the National Airspace System by providing tools for conformance monitoring and increasing situation awareness.
- Improved controller productivity by reducing controller and pilot workload.
- Increased capacity by enabling advanced operations via an effective user interface that will reduce instances of human error.

The FAA plans to implement Data Comm over three segments. The Segment 1 implementation will occur with currently deployed aircraft equipage. Voice radio communications will continue to be the primary means of communication in Segment 1. The Segment 2 implementation will require users to upgrade their equipment to a common level of Data Comm capability. At the beginning of Segment 2, ATCT controllers will have both data link and voice communications available for use, but voice will still be the primary means of communications. Data link will evolve as the primary means of communication by the end of Segment 2; however, controllers will use data link only for non-time-critical messages that do not require a pilot to take immediate action. Voice communications will still enable tactical, time-critical operations that require immediate pilot action, and controllers will still be able to revert to voice communications in the event of a Data Comm failure. ATCT controllers will also use voice communications to interact with aircraft that are not equipped with data link, just as they do today. The Segment 3 implementation (FAA, 2009) will provide additional functionality by accommodating (a) Widespread Four Dimensional agreements, (b) TBOs, (c) Crossing and Passing operations, and (d) Merging and Sequencing operations.

To implement Data Comm, the FAA must conduct concept and operational research to identify the advantages and limitations of data link communications. The Data Comm research will also generate an initial set of system requirements that all stakeholders can use as a foundation for future development.

1.1 Background

Researchers began the examination of Data Comm, or data link, concepts at least 35 years ago (e.g., Diehl, 1975; Hilborn, 1975). Since that time, researchers have continued to examine the implications of Data Comm to further develop delivery methods, examine message response delays, foster controller acceptance, and optimize controller performance and workload (e.g., Ground Data Link Development Team, 1992; Kerns, 1991; Talotta et al., 1992). A large portion of the literature focuses on the en route domain, and some of the literature focuses on the Terminal Radar Approach Control (TRACON) domain. A smaller portion of the literature considers the tower domain (e.g., Jakobi et al., 2009; Stephenson, 2007). The previous research provides insight into how Data Comm may influence communications (Prinzo, 2001; Rakas & Yang, 2007), Graphic User Interface (GUI) design (Kerns, 1991; Stephenson, 2007), controller attention (Metzger & Parasuraman, 2006), and workload (Data Link Benefits Study Team, 1996; Kerns, 1991; Prinzo, 2001).

The Data Link Benefits Study Team (1996) conducted a study to assess the benefits of data link in terminal airspace by simulating Newark airspace in the New York TRACON. They compared operational baseline air traffic data to Human-in-the-Loop (HITL) simulation data that used both voice and digital communications. Nine controllers and three supervisors served as participants. Their findings showed that digital communications in the TRACON airspace improved controller productivity and flight efficiency (e.g., reduced arrival delays), reduced controller workload and stress, and improved safety.

Of course the implementation of Data Comm will affect the communications between controllers and pilots in a number of ways. Data link will shift communications from an auditory mode to a visual mode, and the temporal aspect of communications will also change. Kerns (1991) conducted a literature review of 15 studies to distill strategies for using data link. She only reviewed studies that included realistic simulations of data link in an operational context and that collected measures of controller or pilot performance and opinion. Kerns identified features of the GUI and suggested implications for an overall data link system design. In particular, Kerns recommended that an instruction and the acknowledgment of receipt be given in the same mode. She also provided a set of interface design principles. Kerns recommended (a) that more automated input mechanisms would reduce workload and are generally preferred, (b) that the display of feedback for digital communications should be placed close to the aircraft symbol on the controller's situation display, and (c) that only limited feedback should be provided on transaction failure states and operational acknowledgments. Two of the studies she reviewed showed that data link transactions took twice as long as voice communications. In particular, Talotta, Shingledecker, and Reynolds (1990) found that data link communications took 21 s versus 10 s for voice communications, and Waller and Lohr (1989) found that data link communications took 19 s versus 8 s for voice communications. Kerns' review concluded that data link did not affect workload, but it did redistribute workload across information processing resources by reducing the need for listening and speaking but increasing the need for both visual and manual effort.

To further examine how data link may affect communication and shift cognitive information processing resources, Prinzo (2001) conducted a HITL simulation using eight TRACON controllers. She examined the effects of data link delay (no delay vs. 11 s delay) by collecting both subjective and objective measures of workload and measures of aircraft and communication activity. Prinzo found that verbal communications were longer in length, but they contained the same amount of meaningful information as digital communications. Data link messages took longer to construct and send, but they were more precise. The use of data link also allowed controllers to perform communication tasks in parallel (i.e., simultaneous digital and verbal communications) rather than serially. Prinzo's findings suggested that controller workload will change as the means of communication shifts from a verbal mode to a visual mode because a large part of the controller and pilot tasks are already visually oriented. The data link delay did not seem to affect controllers, but the use of data link itself caused a slight increase in controllers' self-reported workload; these differences were not statistically significant. Data link increased the time required to communicate with pilots by 2 s per transmission. The increased time to communicate did not affect the overall system efficiency, but suggested that data link messages must be easy to construct and issue.

The changes to the temporal aspect of communications caused by data link were further investigated by Rakas and Yang (2007), who examined the potential effects of multiple open transactions on controller performance. They analyzed a database of forty-two, 30-min controller-pilot voice recordings from 33 en route sectors in five Air Route Traffic Control Centers (ARTCCs). Rakas and Yang found that increased multiple open messages may cause miscommunications and delay controller responses to pilot requests. Their overall recommendation was to reduce the delay associated with data link and the number of open messages as much as possible. Consequently, even if the use of data link results in communication delays and more open messages, the number of miscommunications may be mitigated because there will be fewer voice communications that could potentially result in readback and hearback errors.[1]

The potential problems associated with data link delays and open messages stem from the way that controllers must allocate their attentional resources and the fact that data link shifts cognitive resources away from the auditory channel and shifts more attention to the visual channel. Metzger and Parasuraman (2006) conducted an experiment to examine the effects of cueing and traffic density on controller performance and visual attention. They used a medium-fidelity simulator that included a situation display and a separate data link and electronic flight strip display. The participants (Eight controllers from the Washington ARTCC and Potomac TRACON) had to detect conflicts in an air traffic scenario and perform the secondary tasks of using the data link interface and managing flight data. Metzger and Parasuraman provided multimodal alerts (e.g., color and auditory) and varied traffic loads. They measured the number of conflict detections and how soon the participants noticed the conflicts. The participants provided subjective ratings of mental workload and wore an eye and head tracker so the experimenters could measure their eye movements. The results showed that although multimodal cueing did not provide the hypothesized benefits, the participants diverted their visual attention from the situation display to the data link display under high traffic loads. On the basis of their findings, the authors recommended that data link displays should be integrated with existing displays to prevent the diversion of visual attention away from the primary task. Truitt (2006, 2008) has implemented such an integrated GUI in the Tower Operations Digital Data System (TODDS).

Although they examined Data Comm and how data link messages may or may not affect controllers, none of these studies focused on ATCT controllers. Stephenson (2007) reported on a study at Brussels Airport that focused on ATCT controllers and how their use of digital clearances for push back and *initial taxi* affected safety, controller workload, and voice frequency channel load. The study was a field demonstration where controllers issued D-Taxi clearances, but pilots had to read back the clearances via voice for safety purposes. The controllers had a text as well as a graphical representation of the D-Taxi route clearances, and they completed questionnaires whenever they wanted to note a problem. This methodology resulted in a small number of observations, but the controllers provided additional feedback during a debriefing session. Although the author characterized the level of controller exposure to the D-Taxi tools and procedures as “marginal” during this field test and reported that the controllers’ experience and proficiency were not optimal, the results did provide a number of relevant conclusions. The controllers did not report a reduction of workload due to D-Taxi, but this was probably due to the requirement for verbal pilot readbacks of all clearances and the controllers need to verify each readback. About 75% of the controller responses indicated that D-Taxi did not improve the control process and that they preferred voice over D-Taxi. The controllers reported that D-Taxi increased their “heads-down” time, but the author was unable to quantify this finding due to the methodological limitations. About half of the controllers indicated that heads-down time was an issue. The controllers thought that the GUI reduced

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[1] A readback error occurs when a controller transmits information via voice radio communication to a pilot and the pilot must repeat, or read back, the information to the controller but the pilot’s readback is incorrect. A hearback error occurs when a pilot’s readback is incorrect and the controller does not recognize the error.

heads-down time, compared to text only, and a graphical representation of the taxi route simplified route verification. The controllers also reported that D-Taxi became less usable with increased traffic loads and taxiway complexity, but again, this may have been due to the procedure that required pilots to read back all clearances. Stephenson recommended that the D-Taxi interface must be easy to use, fast, and flexible.

Truitt and Muldoon (2009) conducted a HITL simulation that compared current tower operations to predicted future operations during zero-visibility conditions. Sixteen current ATCT controllers participated. Two of the conditions tested by Truitt and Muldoon compared system operations when controllers used paper flight progress strips and ASDE-X to TODDS. In the TODDS condition, all departure aircraft were data link equipped and received D-Taxi clearances (i.e., 100% data link equipage). When the participants used the TODDS, the ramp-waiting time increased due to data link communications, but the number and duration of ground controller-to-pilot transmissions decreased. The duration of taxi-out and taxi-in operations were significantly shorter when the participants used the TODDS, even though there was a significant increase in the duration that aircraft waited on the ramp.

Most recently, Jakobi et al. (2009) provided recommendations for operating procedures and technical and operational requirements for the implementation of “higher level” Advanced Surface Movement Guidance and Control System (A-SMGCS) services. Their recommendations were on findings from multiple studies that were part of the continuing European Airport Movement Management by A-SMGCS (EMMA2) research program. The EMMA2 program examined Data Comm concepts using field studies at three airports (located in Prague Ruzyne, Milan Malpensa, and Toulouse Blagnac), four flight deck simulators, five ATCT simulators, two test aircraft, and several vehicles. They conducted both shadow trials and integrated air-ground simulations. Jakobi et al. reported that D-Taxi clearances reduced the use of the voice radio frequency and that D-Taxi was a promising technology that addresses both safety and efficiency problems. Because the controllers had to provide multiple clearances within a short period of time, the authors recommended that the necessary Human-Machine Interface (HMI) must minimize controller inputs. The EMMA2 project simplified controller inputs for D-Taxi clearances by integrating D-Taxi functions with their electronic flight strip system. Controller inputs were also reduced by an automatic taxi routing function that proposed taxi routes for controllers to accept, modify, or reject. The authors reported that mixed equipage operations did not pose any concerns. They also recommended that future research should include air-ground integration so that researchers can better understand the perspective of both the pilots and controllers while they are working in the same communications loop.

A number of other recent studies have provided the foundation for requirements that support Data Comm Segment 2. Researchers at GMU conducted a series of en route and terminal cognitive walkthroughs (GMU, 2008a; GMU, 2008b). Their findings provided the first requirements iteration for Data Comm Segment 2. The results from four part-task studies and the Future Terminal Workstation (FTWS) research effort will inform the second requirements iteration. Additional part-task studies addressed issues that the cognitive walkthroughs could not resolve (but were too specific for HITL simulations). The part-task studies addressed (a) Multi-Modal Information Presentation, (b) Tailored Arrivals and Data Comm, (c) Conformance Monitoring and Controller Workload, and (d) Party Line Loss Impact and Pilot Performance. Researchers from the Human Factors Team–Atlantic City have also conducted experiments examining the FTWS and the Future En Route Workstation (FEWS) prototypes to investigate controller displays that support integrated NextGen capabilities, including data link communications. A subsequent Data Comm Segment 2 requirements iteration incorporated findings from an en route HITL study as well as a portion of a flight deck HITL study conducted by the National Aeronautics and Space Administration Langley Research Center. The final set of requirements generation activities will incorporate the FTWS, FEWS, ATCT, and the remaining flight deck HITL study results. The FAA will use the results of these studies to develop and identify the Data Comm capabilities for test and evaluation in subsequent HITL experiments. The combined results of these efforts will help to further define the functional requirements for Data Comm Segment 2.

1.2 Purpose

The purpose of this experiment was to assess how D-Taxi may impact ATCT controller workload and performance. The experiment only addressed D-Taxi clearances for departure aircraft (i.e., taxi-out operations). We examined, compared, and contrasted the experimental conditions to answer the following research questions.

- Does D-Taxi affect voice communications?
- Does D-Taxi affect controller workload?
- Does D-Taxi affect controller awareness of airport traffic?
- Are the Data Comm indicators adequate?
- Are the D-Taxi functions easy to use?
- Are controllers able to notice Data Comm failures?
- How do controllers respond to Data Comm failures?

A secondary objective was to assess how D-Taxi may impact airport operations. Therefore, we collected data to answer the following questions.

- Does D-Taxi affect the time required to execute surface operations?
- Does D-Taxi affect arrival and departure rates?

2. METHOD

We conducted the experiment at the FAA Research, Development, and Human Factors Laboratory (RDHFL). The experiment used current ATCT controllers in a high-fidelity, HITL simulation to examine Data Comm Segment 2 ATCT concepts using two levels of aircraft equipage and a voice only, baseline condition in which Data Comm was unavailable. Data Comm capability allowed the participants to receive digital requests for taxi clearances and issue D-Taxi clearances for outbound aircraft. The experiment primarily used a 2 (Run number – First vs. Second) x 3 (Condition – Voice Only, 40% Data Comm, 75% Data Comm) repeated measures design in which the participants experienced all conditions in a counterbalanced order.

2.1 Participants

Sixteen Certified Professional Controller (CPC) ATCT controllers served as participants. Each participant possessed skills at an ATCT facility rated at level 10 or higher. The 14 male and 2 female participants were from Dallas/Fort Worth International, George Bush Intercontinental/ Houston, Miami International, Minneapolis-St. Paul International/Wold-Chamberlin, Orlando International, Salt Lake City International, and Tampa International. Because our simulated ATCT environment was similar to a configuration of Boston Logan International Airport (BOS), controllers from BOS could not participate to ensure valid results. All of the participants had normal or corrected-to-normal vision, but seven of the participants wore corrective lenses during the experiment. The participants completed the Informed Consent Statement (see Appendix A) and the Biographical Questionnaire (see Appendix B). Table 1 shows additional responses to the Biographical Questionnaire.

Table 1. The Participants' Response Means (*M*) and Standard Deviations (*SD*) for Items Numbered 3 through 10 of the Biographical Questionnaire

Item Number	Biographical Questionnaire Item	*M* (*SD*)
3	What is your age?	41.25 (8.48) years
4	How long have you worked as a CPC (FAA & military)?	16.96 (9.58) years
5	How long have you worked as a CPC for the FAA?	14.97 (8.82) years
6	How long have you actively controlled traffic in an ATCT?	13.46 (8.18) years
7	How many of the past 12 months have you actively controlled traffic in an ATCT?	12.00 (0.00) months
8	Rate your current skill as a CPC.	8.19 (0.75)
9	Rate your current level of stress.	3.44 (2.42)
10	Rate your level of motivation to participate in this study.	9.00 (0.82)

2.2 Apparatus

The simulation used the Distributed Environment for Simulation, Rapid Engineering, and Experimentation (DESIREE) along with the Target Generation Facility (TGF), simulation pilot workstations, and a voice communications system. While DESIREE presented the TODDS, the TGF generated aircraft tracks, managed simulation pilot workstations, and presented the out-the-window (OTW) view. The experiment employed six simulation pilots, each with their own workstation and communications system. Three simulation pilots communicated with the ground control position, and three simulation pilots communicated with the local control position. The ATCT simulation platform consisted of three controller workstation displays situated within a 270-degree OTW view that comprised nine, 73″ high definition televisions. A standard 20″ computer monitor presented Standard Terminal Automation Replacement System (STARS) radar data. We mounted the STARS display on an articulated arm that allowed the participants to adjust the viewing angle and height. In addition, two VarTech Systems, Inc. touchscreen displays enabled the TODDS. All of the displays rested on one of two height-adjustable tables. We also placed a Workload Assessment Keypad (WAK; Stein, 1985) on the table at each controller position.

We mounted two cameras and two microphones on the ceiling above the controller positions (one each above the ground control position, and one each above the local control position). The cameras recorded the participants' interactions with TODDS and the microphones recorded the ambient sound in the room. We also mounted a camera in front of the participants to capture each participant's point of gaze (e.g., TODDS, OTW, WAK). We digitally recorded all audio and video data. Computers captured the video data (including a superimposed time stamp) at a rate of 30 frames per second. Figure 1 shows the overall equipment configuration from the participants' point of view.

Figure 1. The experiment apparatus including the ground (foreground) and local (background) control positions and the OTW view. The STARS display (not shown) was located to the right of the local controller.

The TODDS consisted of two touchscreen displays, one for the ground control position and one for the local control position. Each 21.3″ touchscreen had an active display area of 17″ (43.2 cm) wide and 12.75″ (32.4 cm) high with a 1,600 x 1,200-pixel format and had a viewing angle of 85 degrees. The touchscreens used resistive technology that allowed the participants to activate the display surface with their fingertip. We mounted each touchscreen on a stand that supported its weight (30.4 lb, 13.82 kg) and allowed the user to adjust the horizontal and vertical viewing angle and the display height. Each touchscreen had an associated Airport Surface Detection Equipment – Model X (ASDE-X) keyboard and a trackball/keypad as additional input devices.

The TODDS presented the participants with electronic fight data in the form of Flight Data Elements (FDEs), surface surveillance data – including aircraft position and associated data blocks – weather information, and the ability to construct and issue D-Taxi clearances. This integrated design placed all of the most important information on a single display in front of the participants to simplify information presentation and to reduce the participants' need to constantly shift their visual attention among multiple information displays. Figures 2 and 3 present screenshots from the TODDS ground and local control positions. For more information about TODDS, see Truitt (2006, 2008).

Figure 2. Screenshot of the ground control position.

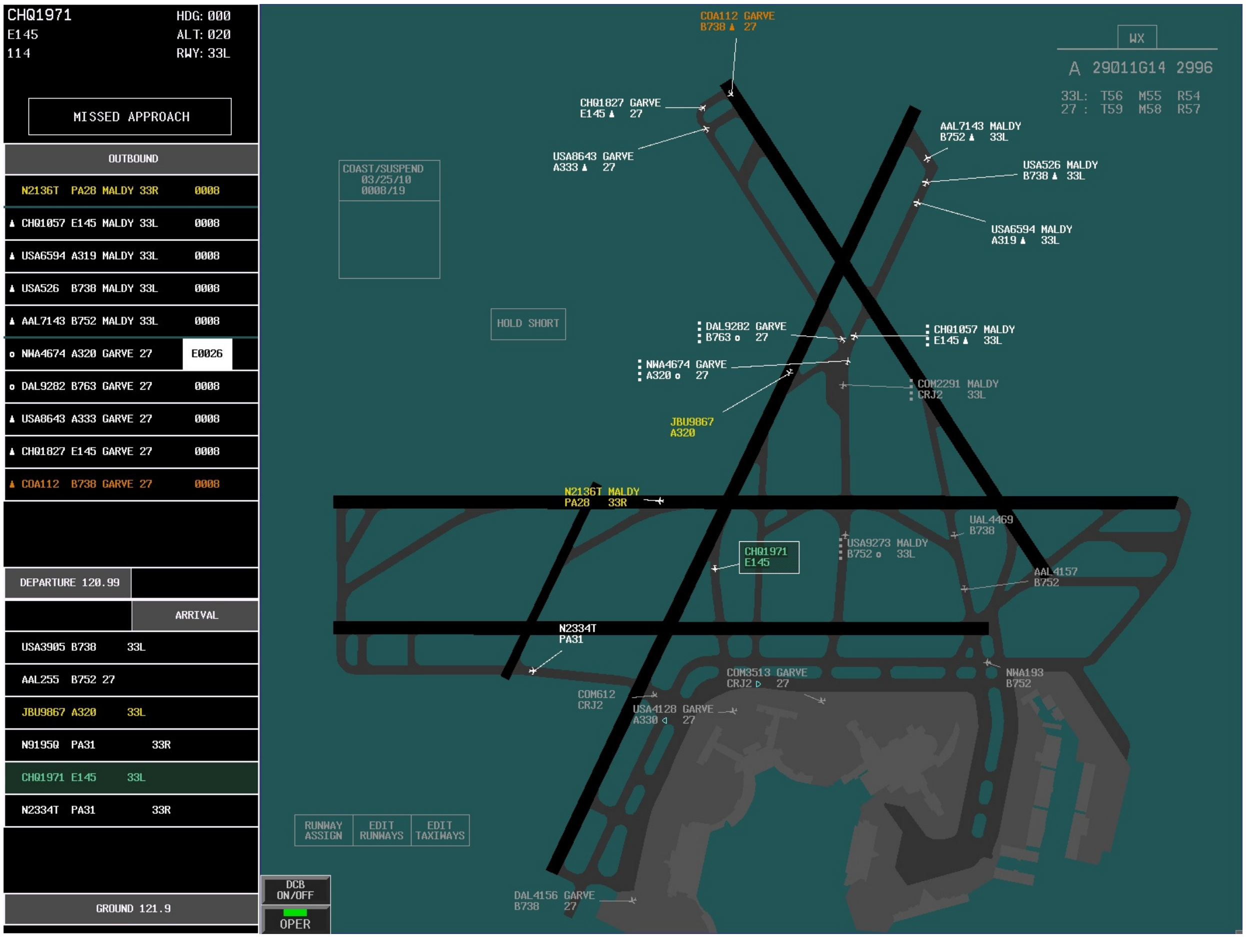

Figure 3. Screenshot of the local control position.

2.3 D-Taxi Interface and Functionality

The original TODDS D-Taxi design only provided controllers with the ability to issue a set of predetermined taxi clearances based on a departure aircraft's initial ramp spot and runway assignment (see Truitt, 2008). When a controller issued a D-Taxi clearance, the computer automatically generated a taxi clearance, including hold short instructions that took the aircraft from a ramp spot to a runway via the most direct route. Controllers could cancel a D-Taxi clearance, but they were unable to modify it in any way. For the current experiment, we built upon the existing TODDS D-Taxi GUI and functionality by providing controllers with a means to modify the taxi clearance. In this section, we present a full description of the TODDS D-Taxi GUI and functionality, including data link indicators, D-Taxi route construction, and taxiway conformance monitoring.

A data link indicator appeared on the TODDS on the left side of the FDE and in the center of the second line of the data block for each departure aircraft that was data link equipped. The data link indicators appeared on the TODDS at both the ground and local control positions, but only the participant operating the ground control position could issue or cancel a D-Taxi clearance. Arrival aircraft that were data link equipped did not display data link indicators because that information was irrelevant for the current experiment where inbound D-Taxi operations were not available.

2.3.1 Data Link Equipment Indicator

Aircraft that were data link equipped had an upright triangle that was either open gray or filled white. An open gray triangle indicated a data link equipped, unowned aircraft; that is, an aircraft that was under the control of another position or that was in a pending status (i.e., waiting on a ramp spot prior to taxi). A filled white triangle indicated a data link equipped, owned aircraft; that is, an aircraft that was under the control of a participant at the currently observed position (ground or local). Only one controller position could own an aircraft at any given time. For example, from the perspective of the TODDS ground control position, both aircraft in Figure 4 are data link equipped, but only the aircraft on the left (CHQ1057) is owned by the ground controller. The aircraft on the right (USA6594) is owned by the local control position. From the perspective of the local control position, the data link indicators appeared in the opposite state (owned vs. unowned) on the TODDS. Although the data link indicator showed that both of these aircraft were equipped, it also showed that neither was taxiing with a D-Taxi clearance.

Figure 4. Data link capability indicators for owned (left) and unowned (right) aircraft.

2.3.2 Pilot Request

When a data link equipped aircraft reached a ramp spot and was ready to taxi, the pilot sent a D-Taxi request via data link to the participant at the ground control position. When the pilot requested a taxi clearance via data link, the data link indicator changed to a light blue triangle and pointed to the left (see Figure 5). The data block appeared in gray because the aircraft was in a pending/unowned status.

Figure 5. Data link indicator indicating a pilot request for taxi instructions.

When the participant at the ground control position noticed the pilot request, he or she then selected the aircraft's data block or FDE to activate the D-Taxi button (see Figure 6). Selecting an aircraft's data block or FDE highlighted the flight data of interest and opened the readout area in the upper corner above the FDE list. The readout area displayed the specific pilot request in addition to the full set of flight data for the selected aircraft (see Figure 7). In the current example, the aircraft's assigned departure runway was runway 27. The pilot's data link request always coincided with the currently assigned runway.

Figure 6. Selected data block and activated D-Taxi button.

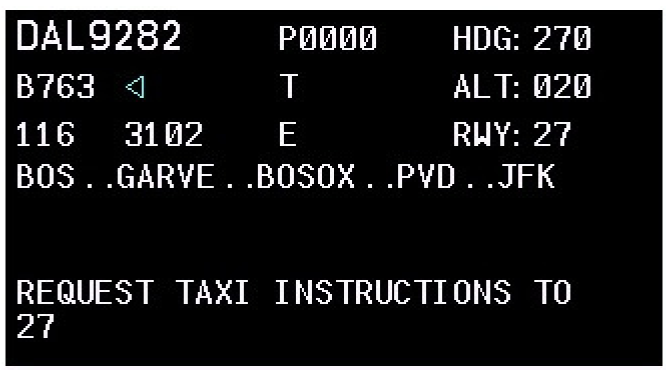

Figure 7. Readout area displaying a data link pilot request (bottom) and the full set of flight data.

2.3.3 Controller Deferred Request

Once the participant selected an aircraft with a data link pilot request, he or she could defer the request, construct and issue a D-Taxi clearance, or issue a taxi clearance via voice. The participant could defer the pilot's request by simply deselecting the aircraft. For a deferred request, the data link indicator appeared as an upright, light blue, open triangle (see Figure 8). Deselecting the aircraft also closed the readout area and deactivated the D-Taxi button. When the participant was ready to issue a D-Taxi clearance for a deferred request, the participant selected the aircraft again to display the readout area and activate the D-Taxi button. The participant then selected the D-Taxi button to enter the D-Taxi construction mode.

Figure 8. Data link indicator for a deferred data link request.

2.3.4 D-Taxi Construction Mode

When a participant selected the activated D-Taxi button to send a D-Taxi clearance to an aircraft, the TODDS entered the D-Taxi construction mode. In the D-Taxi construction mode, the TODDS placed an opaque "screen" over the surface surveillance display that dimmed everything except for the aircraft and related elements of interest. The screen also prevented the participant from selecting or moving other FDEs or data blocks. In addition to the screen, the TODDS presented a proposed taxi route (indicated by a white line) that included hold short points and a set of D-Taxi construction mode buttons (see Figure 9).

Figure 9. The ground control position in the D-Taxi construction mode.

When in the D-Taxi construction mode, the participant used the D-Taxi construction mode buttons (see Figure 10) to edit the taxi route, add or remove hold short points, send the D-Taxi clearance to the pilot, or cancel the D-Taxi construction and return to the normal mode. To edit the taxi route, the participant placed his or her fingertip on one side of the displayed route and then dragged the route to a different taxiway. The TODDS then displayed the new route.

Figure 10. Selected data block and D-Taxi construction mode buttons.

The participant could add or remove one or more hold short points by selecting the Edit HS button. When the participant selected the Edit HS button, a set of hold short edit buttons replaced the D-Taxi construction mode buttons (see Figure 11). The hold short edit buttons provided the participant with possible hold short points for all runways. The D-Taxi feature did not provide a means for holding short of a taxiway. The buttons for hold short points that were already part of the D-Taxi clearance appeared grayed out (e.g., 33L).

Figure 11. Selected data block and edit buttons for adding or removing a hold short point.

The participant could remove a hold short point by selecting a grayed out button. The participant could also add a hold short point by selecting one of the buttons that was not grayed out. Adding a new hold short point grayed out the hold short edit button and placed a D-Taxi hold short indicator on the currently constructed route (see Figure 12). After adding or removing hold short points in the D-Taxi clearance, the participant selected the Edit HS button again to return to the D-Taxi construction mode buttons. If the participant made an error at any time during the D-Taxi construction or wanted to return to the originally proposed taxi route, he or she selected the Reset button to undo any modifications made to the originally proposed route.

Once the participant was satisfied with the D-Taxi route including the hold short points, selecting the Send button transmitted the D-Taxi clearance to the aircraft via data link.

Figure 12. Hold short indicator on a D-Taxi route in the D-Taxi construction mode.

2.3.5 D-Taxi Clearance Sent

Once the participant selected the Send button and transmitted the D-Taxi clearance to the aircraft via data link, the data link indicator in the FDE and data block pointed to the right. As with the pending data link request from the pilot, the D-Taxi sent indicator was a light blue, open triangle (see Figure 13).

Figure 13. Data link indicator in a data block showing that the participant sent the D-Taxi clearance to the aircraft.

After sending the D-Taxi clearance, the participant could select the aircraft again to open the readout area and verify the clearance (see Figure 14). Each D-Taxi clearance included the current ATIS information and the taxi route including hold short points. In the current example, the participant had sent a D-Taxi clearance (ATIS A TAXI 27 VIA E HS 33L) that included ATIS information A (alpha) and instructions to taxi to runway 27 via taxiway E (echo) and to hold short of runway 33L. Note that the appropriate data link indicator (light blue triangle) also appeared in the readout area to the right of the aircraft type (e.g., B763).

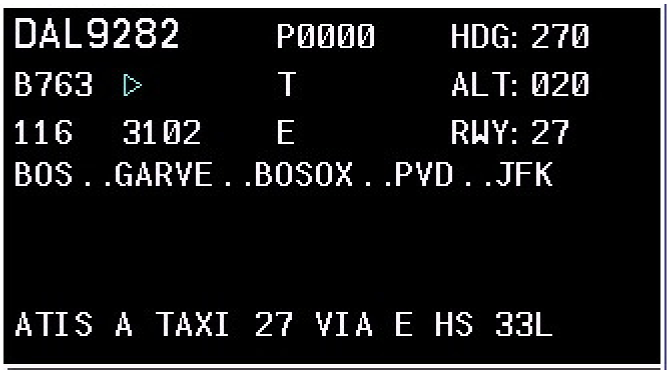

Figure 14. Readout area displaying the D-Taxi clearance sent by the participant (bottom).

2.3.6 D-Taxi Clearance Failure

After sending a D-Taxi clearance to an aircraft, the participant waited for the pilot's response. We programmed the ATCT simulator to simulate a successful data link exchange in most instances, but we also included data link failures. If a data link transmission failed, the data link indicator turned red (see Figure 15). When the participant noticed that a data link transmission had failed, he or she could resend the D-Taxi clearance or contact the pilot on the ground control voice radio frequency and issue the taxi instructions by voice. An aircraft that failed to receive a data link transmission continued to display the failed data link indicator to remind the controller of the aircraft's status.

Figure 15. Data link indicator showing a failed data link transmission.

We also programmed the ATCT simulator to simulate a complete data link failure where all data link capabilities were lost. We designed this total data link failure to simulate a facility-wide outage where no digital transmissions were possible. When a total data link failure occurred, all data link indicators disappeared from the TODDS on both the local and ground control positions, and the aircraft data blocks and FDEs appeared as they would if the aircraft were not data link equipped. A complete data link failure also caused the D-Taxi button label and outline to turn red and a red flashing "X" appeared over the button. The participant could select the flashing red "X" to stop the flashing, but the red "X" remained. Once the data link service was restored, all of the data link indicators returned, the D-Taxi button became functional again, and the participant resumed issuing D-Taxi clearances.

2.3.7 D-Taxi Clearance Accepted

If the data link transmission was successful and the pilot accepted the D-Taxi clearance, then the D-Taxi accepted indicator (an unfilled circle) appeared in the aircraft's data block and FDE. If the D-Taxi clearance included a hold short clearance, then the hold short indicator also appeared on the left side of the aircraft's data block (see Figure 16). After noticing the D-Taxi accepted indictor, the participant could then contact the pilot on the ground control voice radio frequency and tell the pilot to "resume taxi" to begin the taxi operation as instructed in the D-Taxi clearance. We required the participant to initiate a taxi movement via voice radio contact with the pilot to establish that voice communication was operational and to allow the participant to control the sequence and timing of departure aircraft onto the airport movement area.

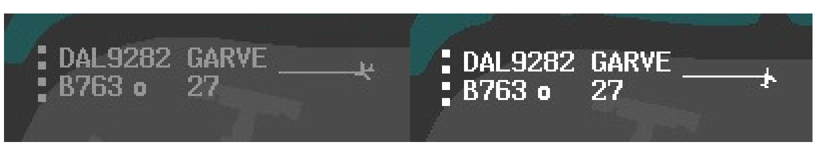

Figure 16. Data link indicator and hold short indicator for an unowned (left) and owned (right) aircraft showing that the pilot accepted a D-Taxi clearance.

Once the participant told the pilot to resume taxi, the participant then moved the aircraft's FDE from the Pending list to the Outbound list to assign a taxi time and to change the color of the aircraft's flight data from pending/unowned (gray) to owned (white).

After the participant issued a D-Taxi clearance and the pilot accepted it, the participant could select the aircraft's data block or FDE at any time to display the aircraft's full set of flight data in the readout area including the D-Taxi clearance (see Figure 17).

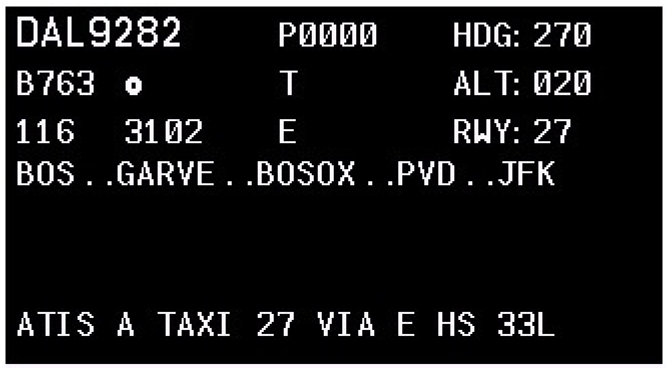

Figure 17. Readout area displaying the accepted D-Taxi clearance and data link indicator (D-Taxi accepted).

2.3.8 D-Taxi Cancellation

After the pilot accepted a D-Taxi clearance, the participant could cancel the D-Taxi clearance at any time. To cancel a D-Taxi clearance, the participant selected the aircraft's data block or FDE to activate the D-Taxi cancel button and then selected the D-Taxi cancel button. The TODDS only activated the D-Taxi cancel button when the participant selected an aircraft that had a D-Taxi accepted indicator in the data block and FDE. Once the participant canceled a D-Taxi clearance, the data link indicator changed to the appropriate owned or unowned data link capability indicator, as shown previously in Figure 4.

The participants could only construct and send a D-Taxi clearance to aircraft that were still on the ramp. Although the participants could cancel and reissue a D-Taxi clearance to an aircraft while it was still on the ramp, they could not cancel and reissue a taxi clearance to an aircraft once the aircraft moved off of the ramp spot. This limitation was due to the ATCT simulator's method of calculating a taxi route based on static points (i.e., ramp spot to runway) rather than on the actual position of the aircraft. Because D-Taxi was intended for use only in strategic, not tactical, control of aircraft movements due to the time delay associated with data link functionality, we determined that such a limitation would not affect the initial examination of the D-Taxi concepts. Future versions of the D-Taxi functionality should account for this shortcoming to provide the participant with more flexibility and to further examine the strategic versus tactical use of data link on the airport surface.

2.3.9 Taxiway Conformance Monitoring

Aircraft that taxied using a D-Taxi clearance were subject to taxiway conformance monitoring. When an aircraft on a D-Taxi clearance did not conform to the expected taxi route, the text of the aircraft's data block and FDE flashed between red and the current color (gray, white, yellow, or light blue). The flashing appeared on both the ground and local control positions of TODDS and continued until one of the participants selected the flashing data block or FDE. The data block and FDE continued to display with red text (see Figure 18) until the aircraft taxied back onto the correct route, or until the participant at the ground control position canceled the D-Taxi clearance by selecting the aircraft's data block or FDE and then selecting the D-Taxi cancel button. If the participant chose to cancel the D-Taxi clearance, he or she then issued a new taxi clearance to the pilot via the voice radio frequency.

Figure 18. Data block of an aircraft that violated the D-Taxi clearance.

2.3.10 Data Link Delay Modeling

We simulated a data link delay to account for the time needed (a) to transmit the D-Taxi clearance to the aircraft, (b) for the pilot to notice and read the D-Taxi clearance and construct a reply, and (c) for the pilot to transmit a response back to the participant. To simulate the delay caused by the data link transmission itself, sometimes referred to as a Logical Acknowledgment (LAK) delay, we used a distribution that generated LAK delays ranging between 1 s and 5 s, but the distribution was skewed to favor shorter LAK delays. To describe the distribution in a meaningful way, we generated a sample distribution of LAK delays with a 100,000 trial Monte Carlo simulation. Table 2 presents the results of the Monte Carlo simulation. We used this same distribution to simulate the LAK delay between the ground control position and the aircraft and the LAK delay between the aircraft and the ground control position.

Table 2. Number, Percentage, and Cumulative Percentage of Occurrences from a 100,000 Trial Monte Carlo Simulation of the LAK Delay Distribution Function

Seconds	Occurrences	%	Cumulative %
1	22969	22.969	22.969
2	27418	27.418	50.387
3	25088	25.088	75.475
4	17619	17.619	93.094
5	6906	6.906	100.000

To simulate the delay associated with pilot response time, we used a distribution that generated pilot response delays that ranged between 6 s and 17 s. Like the LAK delay distribution, the pilot response delay was skewed to favor shorter response times. Table 3 shows the results of the 100,000 trial Monte Carlo simulation. Almost 95% of the pilot response delays ranged between 6 s and 11 s, and longer delays occurred relatively infrequently. We favored shorter response times for pilots because when making a request to taxi, the aircraft is stopped on the ramp or at the gate, and the pilot would be waiting for a controller response.

Table 3. Number, Percentage, and Cumulative Percentage of Occurrences from a 100,000 Trial Monte Carlo Simulation That Used the Pilot Response Delay Distribution Function

Seconds	Occurrences	%	Cumulative %
6	19388	19.388	19.388
7	23447	23.447	42.835
8	21398	21.398	64.233
9	15175	15.175	79.408
10	9277	9.277	88.685
11	5444	5.444	94.129
12	2879	2.879	97.008
13	1530	1.530	98.538
14	769	0.769	99.307
15	344	0.344	99.651
16	202	0.202	99.853
17	78	0.078	99.931

By combining the results of the LAK delay distribution and the pilot response delay distribution, we can describe the total data link delay distribution that the participants experienced. As shown in Table 4, the total data link delay distribution ranged between 8 s and 29 s, with 94% of the delays ranging between 8 s and 17 s.

Table 4. Number, Percentage, and Cumulative Percentage of Occurrences from a 100,000 Trial Monte Carlo Simulation of the Total Data Comm Delay Distribution Function

Seconds	Occurrences	%	Cumulative %
8	1065	1.065	1.065
9	3678	3.678	4.743
10	7770	7.770	12.513
11	12162	12.162	24.675
12	15130	15.130	39.805
13	16154	16.154	55.959
14	14325	14.325	70.284
15	11296	11.296	81.580
16	7583	7.583	89.163
17	4776	4.776	93.939
18	2810	2.810	96.749
19	1614	1.614	98.363
20	825	0.825	99.188
21	441	0.441	99.629
22	169	0.169	99.798
23	101	0.101	99.899
24	59	0.059	99.958
25	22	0.022	99.980
26	10	0.010	99.990
27	3	0.003	99.993
28	5	0.005	99.998
29	2	0.002	100.000

2.4 Airport Traffic Scenario Development

Subject Matter Experts (SMEs) used an airport layout (see Figure 19), which was based on BOS, to develop one 40-min base air traffic scenario for practice and testing. They developed the scenario for the 27/33 runway configuration, which we selected for its prototypical qualities. Our SMEs validated that the 27/33 runway configuration was prototypical because it provided both crossing and parallel runway operations at a fairly busy airport.

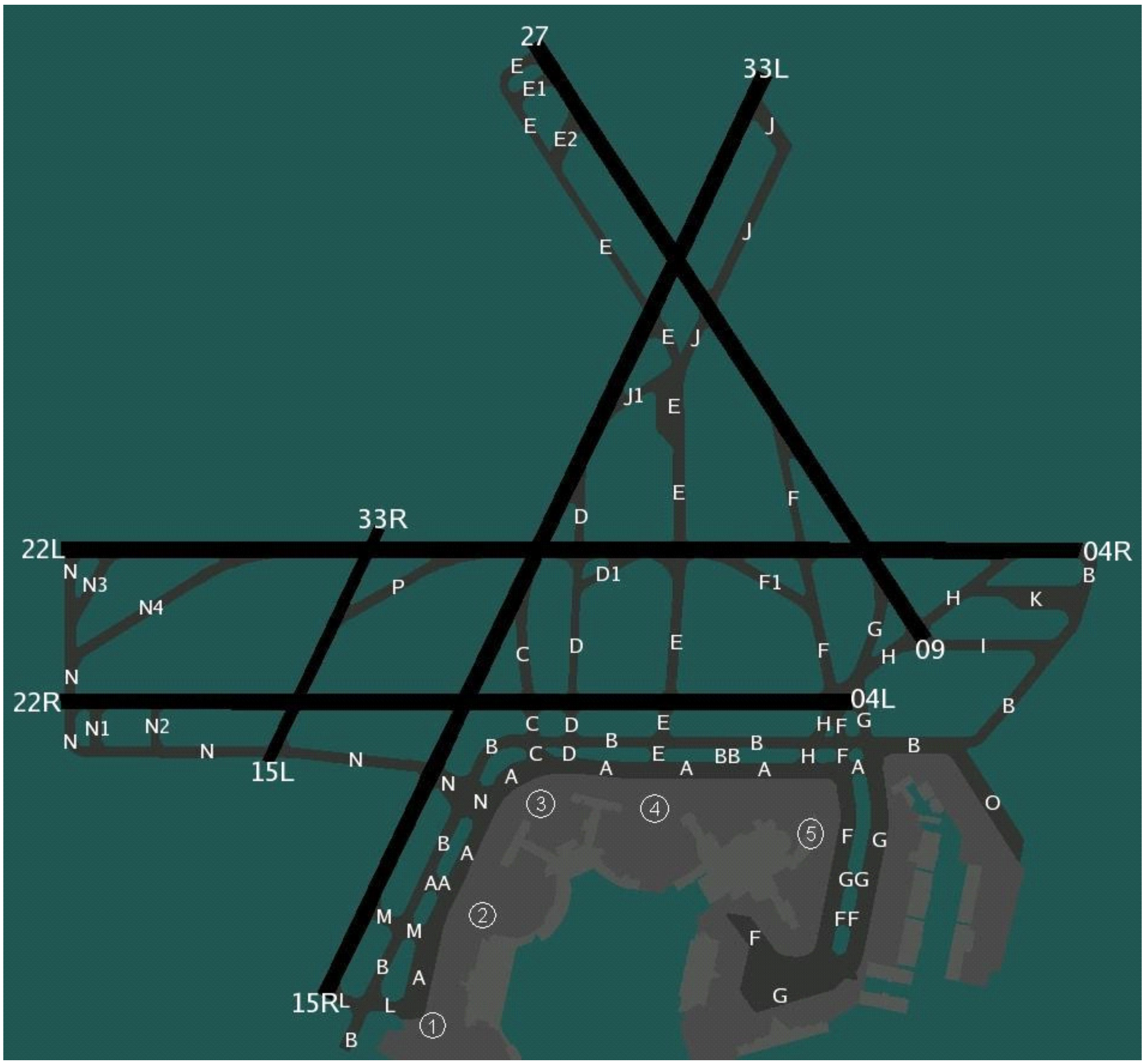

Figure 19. Genera airport including labeled runways, taxiways, and ramp spots (circled numbers). The map is oriented to match the participants' out-the-window view from the tower.

Aircraft in the base air traffic scenario arrived and departed on runways 33L, 33R, and 27. Departure aircraft taxied from ramp spots 1, 3, and 4; Arrival aircraft taxied to ramp spots 2 and 5 (whichever was closest to the end of the arrival runway). We examined the traffic counts for BOS during 2007 and 2008 to determine the traffic counts for their busiest days using the 27/33 runway configuration. We determined a maximum average departure rate of 42 aircraft per hour and a maximum average arrival rate of 36 aircraft per hour. The SMEs constructed the base air traffic scenario to mimic these maximum arrival and departure rates. This high traffic load scenario kept pressure on the runways and helped determine what effect, if any, the Data Comm Segment 2 concept may have on airport efficiency and controller workload and performance.

The SMEs modified the base air traffic scenario by changing the aircraft call signs to create 14 different versions of the same scenario. By changing only the aircraft call signs, without changing the basic traffic pattern, we reduced the potential effects of traffic demand while preventing the participants from recognizing identical scenarios. We presented the different versions of the scenarios to the participants, using a different random order for each group.

During the practice and experimental scenarios, a scripted data link failure occurred for one aircraft in each scenario. The data link failure occurred during the second half of the scenario and always occurred for the same aircraft. Because the participants received a different version of the base air traffic scenario during each run, the aircraft that experienced a data link failure always had a different call sign. The data link failure was likely to occur at different times during each run because it occurred in the second half of the scenario, and there was more time for the participants to influence the flow and timing of the scenario.

The exploratory scenario differed from the practice and experimental scenarios because it only lasted for 30 min and a total data link failure occurred 10 min into the scenario. The data link failure lasted for 10 min, during which time all aircraft lost data link communications. The data link failure was followed by a complete return to service 20 min into the scenario, and normal operations continued for the last 10 min of the scenario.

2.5 Procedure

The participants worked in groups of two. We tested one group of participants at a time. Except for one group, all participants traveled on Monday and Friday, and testing occurred Tuesday through Thursday. Due to laboratory scheduling, one group of participants traveled on Tuesday and Saturday, and testing occurred Wednesday through Friday. When the participants arrived at the RDHFL, each participant, the Principal Investigator, and a witness signed an Informed Consent Statement (see Appendix A). The participants completed the Biographical Questionnaire (see Appendix B) and received a briefing on the schedule of events (see Table 5) and an overview of the experiment. Next, the Principal Investigator and the SMEs provided an overview of the airport and procedures that the participants would use. The participants received an airport map – with designated runways, taxiways, and ramp spots – along with a copy of the entire in briefing documentation. The participants were able to ask questions during the in briefing, until they felt that they had a basic understanding of the airport and the associated procedures. When the in briefing concluded, the participants completed the touchscreen training protocol.

Table 5. Schedule of Events

Time	Day 1	Time	Day 2	Time	Day 3
0830	Informed Consent, In Briefing	0830	Practice Scenario 3	0830	Test Scenario 3
0900	Touchscreen Training	0930	Break	0930	Break
1200	Lunch	0945	Practice Scenario 4	0945	Test Scenario 4
1300	TODDS Training	1045	Break	1045	Break
1345	Break	1100	Practice Scenario 5	1100	Test Scenario 5
1400	TODDS Training	1200	Lunch	1200	Lunch
1445	Break	1300	Practice Scenario 6	1300	Test Scenario 6
1500	Practice Scenario 1	1400	Break	1400	Break
1600	Break	1415	Test Scenario 1	1415	Exploratory Scenario 1
1615	Practice Scenario 2	1515	Break	1500	Break
1700	End of Day	1530	Test Scenario 2	1515	Exploratory Scenario 2
		1700	End of Day	1600	Break
				1615	Post-Experiment Questionnaire
				1630	Out Briefing

2.5.1 Touchscreen Training Protocol

Before starting the touchscreen training scenarios, the participant read the Touchscreen Training Instructions (see Appendix C). The experimenter then demonstrated "hits" and "misses" for each of the three tasks (selecting a single button, selecting two buttons consecutively, and dragging a button to a target area) and the participant performed five practice trials with each task. Before starting the touchscreen training, the experimenter summarized the touchscreen training protocol and answered any questions that the participants had. During the summary, the experimenter emphasized that the participants should perform all of the tasks and trials as accurately as possible and that they should not sacrifice accuracy for speed.

During the touchscreen training, each participant stood in front of a touchscreen with their body centered on the touchscreen to minimize parallax errors (i.e., errors due to off-angle viewing). Before the touchscreen training began in earnest, the experimenter adjusted the touchscreen height and viewing angle to ensure that the participant was looking directly at the screen. The touchscreen training protocol consisted of three specific tasks, each performed with 10 different button sizes across multiple trials. The participant completed a total of 30 different scenarios by performing three tasks with each of 10 different button sizes. The three tasks were to select a single button, select two buttons in sequence, and drag a button to a target area. The size of the target area for the drag task was approximately 50% larger than the button size. The button sizes (in number of pixels) in order of presentation were 140 x 140, 70 x 70, 328 x 40, 170 x 40, 122 x 38, 106 x 40, 96 x 40, 75 x 38, 45 x 48, and 42 x 40. The touchscreen training started with the first task and the first button size. The participant performed all three tasks for that button size. The buttons (and target zone in the third task) appeared at random locations on the touchscreen. After completing all three tasks for a button size, the participant performed all three tasks with the next button size. The buttons continued to generally decrease in size and change shape until the participant had performed all three tasks for each of the 10 button sizes. After completing a scenario, the participant had the option of taking a break before starting the next scenario.

The participant used the index finger of their dominant hand and performed a minimum of 50 trials and a maximum of 100 trials during each scenario. The participant had to achieve a streak of 10 successful trials in a row, and the streak had to occur at or after of the minimum number of trials. For example, if the participant performed trials 41 through 50 without an error – that is, 10 consecutive hits – the scenario ended because they had completed a streak of 10 and completed the minimum number of trials. If the participant had not achieved a streak of 10 consecutive hits after reaching the minimum number of trials, the scenario continued until they achieved the streak or until they reached the maximum number of 100 trials. The participants could view a running tally of their streak length, hits, and misses in the bottom right-hand corner of the touchscreen.

During each trial, the color of the button border changed from white to green when the participant completed a successful trial (i.e., a hit). The color of the button border changed from white to red when the participant failed a trial (i.e., a miss). A miss was recorded if the participant's touch landed outside of a button's border or if they touched and dragged a button simultaneously during a selection task. Therefore, touches required accuracy and concentration. The dragging task required the participant to select and drag a button into a target area. When dragging a button across the screen, the participant's fingertip had to remain in contact with the touchscreen. Lifting the finger from the touchscreen before placing the button completely inside the target area resulted in a miss.

2.5.2 TODDS Training

After the participants completed the touchscreen training, they received training on TODDS. We provide an outline of the training protocol for TODDS in Appendix D.

During the TODDS training, the participants performed each task (e.g., transfer flight data, assign new runway, issue D-Taxi clearance) to demonstrate their understanding. If a participant was unable to complete a task, the experimenter demonstrated the task and asked the participant to perform the task again. Training continued until both participants in the group understood and were able to perform all of the TODDS tasks.

2.5.3 Practice Scenarios

After receiving the TODDS training, the participants began controlling airport traffic scenarios from the ground and local control positions. The participants stood during all scenarios. They completed six 40-min practice scenarios by working at both the ground and local control positions in each of three conditions. The participants worked two consecutive scenarios in each condition so that they could control traffic from both the ground control and local control positions under the same condition. In the baseline Voice Only condition (Condition 1), the participants managed airport traffic without data link capability. In the 40% Data Comm condition (Condition 2), the participants managed airport traffic with 40% of the departure aircraft data link equipped. In the 75% Data Comm condition (Condition 3), the participants managed airport traffic with 75% of the departure aircraft data link equipped. We counter-balanced the order in which the participants experienced the conditions according to Table 6.

Table 6. Scheme for the Counterbalancing of Conditions

Group	Order of Conditions		
1	1	2	3
2	1	3	2
3	2	1	3
4	2	3	1
5	3	1	2
6	3	2	1
7	1	2	3
8	1	3	2

Prior to each scenario, the participants conducted a communications check with the simulation pilots to ensure the quality of voice communications with each pilot. We resolved all communication problems before starting a scenario. The experimenter then provided the participants with instructions for the subsequent scenario. The experimenter reminded the participants of the most common TODDS actions and told them which experimental condition they would experience. The experimenter also provided information about aircraft that were already on the airport surface (e.g., communications status, current taxi operations).

After the second practice scenario (the beginning of Day 2), the experimenter introduced the participants to the WAK by reading the instructions provided in Appendix E. We waited until the third practice scenario to introduce the WAK so that the participants could focus on learning the airport procedures and the TODDS interface during the first two scenarios. The WAK prompted the participants for a workload rating every 5 min by making a brief high-pitched tone and illuminating the WAK buttons. The participants had 20 s to make a response after each WAK prompt. During the practice scenarios, we reminded the participants to make a WAK rating at each prompt, if they failed to do so.

The participants and simulation pilots took a 20-min break at the end of each practice scenario while the experimenters prepared the ATCT simulator for the next scenario.

2.5.4 Experimental Scenarios

Once the practice scenarios were completed, the participants controlled six 40-min experimental scenarios by working at both the ground and local control positions during each of the three conditions. The participants stood during all scenarios. We used the same counterbalancing order for the experimental scenarios that the group experienced with the practice scenarios. Traffic levels remained constant across all conditions as previously described in section 2.4, Airport Traffic Scenario Development.

The experimenter provided the WAK instructions and informed the participants of the experimental condition prior to each scenario. During each 40-min scenario, the participants were responsible for controlling the airport traffic and maintaining flight data for each aircraft. At the end of each experimental scenario, the participants completed the Post-Scenario Questionnaire (PSQ; see Appendix F). After a break, the participants then switched controller positions, as necessary, and completed another 40-min scenario.

2.5.5 Exploratory Scenarios

After completing all of the practice and experimental scenarios, the participants controlled traffic during two 30-min exploratory scenarios. Each participant controlled one exploratory scenario from the ground control position and one from the local control position. During the exploratory scenarios, 75% of the aircraft were data link equipped. The exploratory scenarios presented the participants with a complete data link failure to assess their ability to detect and react to such a failure.

All data link functions failed 10-mins into the exploratory scenario. The TODDS notified the participants of the failure by removing all of the data link indicators located in the aircraft data blocks and flight data elements. To further indicate that data link was unavailable, a red “X” appeared over the D-Taxi button and the D-Taxi button was disabled. The aircraft were in various states of data link activity when the failure occurred, including (a) requesting a D-Taxi clearance, (b) receiving a D-Taxi clearance, (c) acknowledging a D-Taxi clearance, or (d) executing a D-Taxi clearance. We were not able to control what state the aircraft were in when the failure occurred because the aircraft states depended on the participants’ previous actions. The data link failure lasted for 10 min and then returned to service 20 min into the scenario.

The participants also encountered two aircraft that failed to conform to their taxi clearances during the exploratory scenario. The ground controller provided taxi clearances via the voice radio frequency to 25% of the aircraft – one of which violated the taxi clearance by turning onto an incorrect taxiway. The ground controller provided taxi clearances via D-Taxi to 75% of the aircraft – one of which violated the clearance by turning onto an incorrect taxiway. We scripted the nonconformance events to ensure that an experimenter executed the same incorrect taxi movement for the nonconforming aircraft at approximately the same time during each exploratory scenario. The nonconformance event always occurred for a departure aircraft that started at ramp spot 4. As previously shown in Figure 19, the experimenter instructed the nonconforming aircraft to turn left onto taxiway A, then turn right onto taxiway D, then turn right on taxiway D1, before rejoining taxiway E at the runway 04R/22L intersection.

3. RESULTS AND DISCUSSION

To answer the research questions, we collected a variety of objective and subjective measures. The analyses focused on the effects of different levels of data link equipage in comparison to voice only operations. For the exploratory scenarios, we observed the participants' ability to manage data link failures and taxi conformance violations, and the participants provided subjective data via the Post-Experiment Questionnaire (PEQ; see Appendix G). We also summarize the recommended solutions for usability problems. We provide summary information for the PEQ and objective TODDS usability data for D-Taxi operations.

We conducted inferential statistical analyses on the data collected during the experimental scenarios and on the PSQ using a 2 (Run Number – First vs. Second) x 3 (Condition – Voice Only, 40% Data Comm, 75% Data Comm) repeated measures Analysis of Variance (ANOVA). We conducted this two-way ANOVA as needed to detect a main effect of Run or any meaningful interactions that showed an effect of Run within Condition. This analysis determined whether there were any learning effects that may have influenced the outcome of the experiment. If no learning effects were present, we collapsed the data across the Run variable and conducted a one-way repeated measures ANOVA to test the main effect of Condition. Before conducting ANOVAs, we checked the dataset for outliers by using a two-sided Grubbs (*G*) test (Grubbs, 1969; Stefansky, 1972) with $\alpha \leq .05$. We replaced outliers with the variable mean. We analyzed any significant main effects and interactions using the Tukey Honestly Significant Difference (HSD) post hoc test. All analyses used criteria of $\alpha \leq .05$. We report effect sizes (i.e., *partial* η^2) for significant effects. Each graph presents means and standard error bars; see Appendix H for a complete justification of the statistical methods.

3.1 Airport System Data

We used the TGF software to collect airport system data, including the duration that departure aircraft waited on the ramp; duration of taxi-out operations; duration of taxi-in operations; number and duration of delays; and number of arrivals and departures.

3.1.1 Duration on Ramp

The TGF software calculated the duration that each departure aircraft waited on the ramp by recording the time elapsed from when an aircraft first occupied a ramp spot until the aircraft made its first taxi movement. We used these data to calculate the mean duration that departure aircraft waited on the ramp before beginning to taxi in each condition.

There was a significant effect of Condition on the duration that aircraft waited on the ramp, $F(2, 30) = 9.81$, $p < .001$, *partial* $\eta^2 = .40$. Aircraft waited on the ramp longer in the 40% Data Comm condition and in the 75% Data Comm condition compared to the Voice Only condition, $HSD(30) = 11.73$, $p = .005$ and $p < .001$, respectively (see Figure 20).

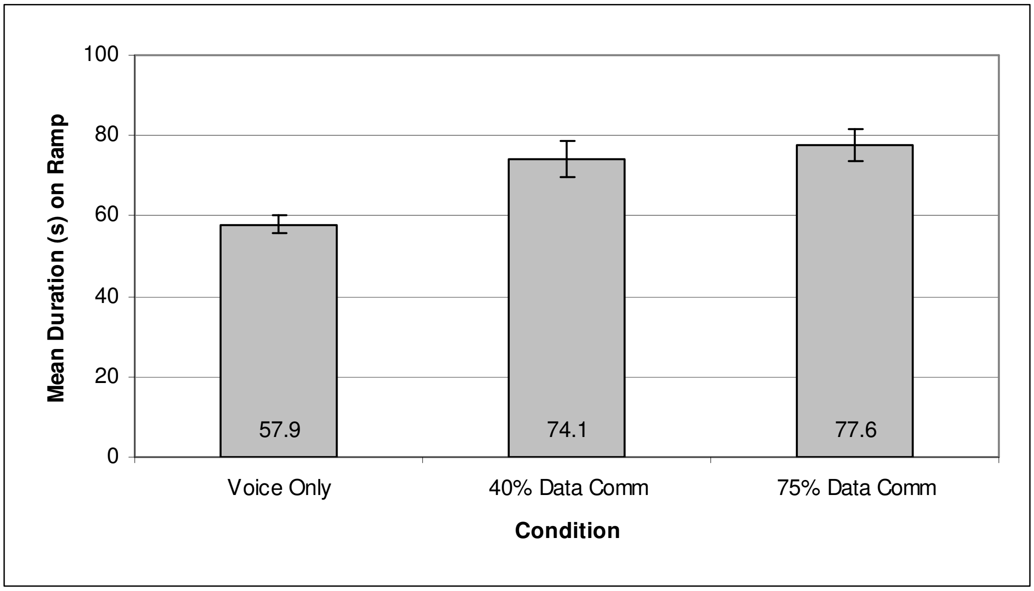

Figure 20. Mean duration that aircraft waited on the ramp before an initial taxi movement by condition.

Aircraft waited on the ramp longer during the Data Comm conditions compared to the Voice Only condition because of the various transmission delays that were associated with data link. In the Voice Only condition, the participants and simulation pilots communicated as controllers and pilots do today. When an aircraft reached a ramp spot and was ready to taxi, the pilot called the ground controller via the voice radio frequency and requested a taxi clearance. The participant then provided a taxi clearance that was read back by the pilot before the aircraft began to taxi. In contrast, with data link, the participant first had to notice that a pilot had made a request via the data link indicator. The participant then used the TODDS D-Taxi function to construct and send a taxi clearance to the pilot. As described previously in section 2.3.10, Data Link Delay Modeling, it took time for (a) the data link to send the message to the aircraft (LAK delay), (b) the pilot to read and understand the taxi clearance, (c) the pilot to respond with a WILCO (will comply) via data link, (d) the data link to send the message to the controller (LAK delay), (e) the participant to notice the D-Taxi Accepted indicator, and (f) the participant to call the pilot via the voice radio frequency and instruct him to "resume taxi." Although D-Taxi clearances resulted in aircraft waiting on the ramp for longer periods of time before beginning to taxi, the increase in data link equipage from 40% to 75% did not affect the average length of this duration.

3.1.2 Duration of Taxi Out

The TGF software calculated the duration of the taxi-out time for each departure aircraft by recording the time elapsed from the first taxi movement until the aircraft's wheels left the runway (i.e., takeoff). We then calculated the mean duration of all taxi-out operations in each condition.

The Grubbs test detected two outliers in the dataset; one from Run 2 of the 40% Data Comm condition, $G = 2.24$, $p = .016$, and one from Run 2 of the 75% Data Comm condition, $G = 2.20$, $p = .024$. The same participant was working at the local control position during both of these data collection runs. There was no evidence of a learning effect on the duration of taxi-out operations. Although the main effect of Condition was not significant, the mean taxi-out duration generally decreased as Data Comm capabilities increased from the Voice Only ($M = 1015.89$ s, $SD = 137.43$)

to 40% Data Comm (*M* = 982.26 s, *SD* = 82.99) to 75% Data Comm (*M* = 963.81 s, *SD* = 132.33). We hypothesize that holding aircraft on the ramp longer as a result of data link delays resulted in less congestion on the taxiways and afforded equivalent, if not operationally more efficient, taxi-out operations overall.

3.1.3 Duration of Taxi In

Even though the participants used D-Taxi only for taxi-out operations, we examined taxi-in operations as well because the ground controller had to manage both types of operations. A change in taskload associated with taxi-out operations may have impacted the ground controller's ability to manage taxi-in operations. We used the TGF software to calculate the mean duration of taxi-in operations for arrival aircraft. We measured the duration of taxi-in operations by recording the time elapsed from when an arrival aircraft's wheels touched down onto the runway until the aircraft reached the designated ramp spot.

The Grubbs test detected an outlier in the dataset for Run 2 of the Voice Only condition, $G = 2.21$, $p = .022$. The differences between the mean durations for taxi-in operations in the Voice Only (*M* = 227.63 s, *SD* = 16.34), 40% Data Comm (*M* = 225.16 s, *SD* = 28.26), and 75% Data Comm (*M* = 229.24 s, *SD* = 25.39) conditions were negligible and not statistically significant.

3.1.4 Number and Duration of Delays

We used the TGF software to measure both the number and duration of delays. On the basis of our SMEs' analysis of the airport and runway configuration, we classified a delay as any taxi-out operation duration that exceeded 20 min. We report the delay durations as the amount of time that elapsed in excess of the 20 min delay criteria. For example, a delay of 5 min means that the aircraft took a total of 25 min to taxi out (i.e., 20 min + 5 min delay).

There was no evidence of a learning effect for either the number or duration of delays. The mean number of delays in the Voice Only (*M* = 5.50, *SD* = 4.34), 40% Data Comm (*M* = 4.50, *SD* = 3.54), and 75% Data Comm (*M* = 4.19, *SD* = 3.63) conditions were not statistically different from one another. The Grubbs test identified two outliers in the dataset for the mean duration of delays. One outlier was present in the dataset for Run 2 of the Voice Only condition, $G = 2.38$, $p = .001$, and one for Run 2 of the 75% Data Comm condition, $G = 2.40$, $p < .001$. The same participant generated both of these outliers, which exceeded 10 min in duration. Although the mean duration of delays (i.e., time exceeding 20 min) in the 40% Data Comm (*M* = 104.24 s, *SD* = 76.06) condition was about 11 s shorter than in the 75% Data Comm (*M* = 115.66 s, *SD* = 87.64) condition, these conditions did not statistically differ from one another, nor did they differ from the Voice Only (*M* = 107.83 s, *SD* = 84.63) condition. Neither the presence nor level of data link equipage affected the number or duration of delays.

3.1.5 Number of Arrivals and Departures

The TGF software counted the number of arrivals that occurred during each experimental run. We identified three outliers from this dataset. The outliers occurred during Run 1 of the Voice Only condition, $G = 2.25$, $p = .015$, Run 2 of the 40% Data Comm condition, $G = 2.40$, $p < .001$, and Run 2 of the 75% Data Comm condition, $G = 2.15$, $p = .040$. With 29 arrivals occurring on average in each condition, there was very little variability in the dataset and the statistical analysis did not detect a learning effect or any effect of Condition.

The TGF software also counted the number of departures that occurred during each experimental run. There was one outlier in this dataset that occurred during Run 1 of the 40% Data Comm condition, $G = 2.17$, $p = .035$. Thirty-three departures occurred on average during each Condition. There was no significant effect of Run Number or Condition on the number of departures.

3.2 Voice Communications

The DESIREE software recorded all Push-To-Talk (PTT) data, including the number of times participants or simulation pilots keyed their microphone to make radio transmissions, the radio frequency they used (ground or local), and the duration of each radio transmission.

3.2.1 Ground Controller to Simulation Pilots

There was no statistical difference between the number of radio transmissions made from the participant at the ground control position to the simulation pilots in the Voice Only ($M = 154.19$, $SD = 22.05$), 40% Data Comm ($M = 155.69$, $SD = 18.55$), and 75% Data Comm ($M = 150.56$, $SD = 22.46$) conditions.

There was one outlier in the dataset for the duration of radio transmissions from the participant at the ground control position to the simulation pilots during Run 2 of the 75% Data Comm condition, $G = 2.21$, $p = .022$. There was no evidence of a learning effect, but there was a significant effect of Condition, $F(2, 30) = 18.67$, $p < .001$, *partial* $\eta^2 = .55$ (see Figure 21). The post hoc test showed that all three conditions were different from one another, $HSD(30) = .25$. The participants made shorter radio transmissions in the 40% Data Comm condition and in the 75% Data Comm condition compared to in the Voice Only condition, $p = .008$ and $p < .001$, respectively. The participants also made shorter radio transmissions in the 75% Data Comm condition compared to in the 40% Data Comm condition, $p = .021$. Overall, the participants made shorter radio transmissions on average as the level of Data Comm equipage increased.

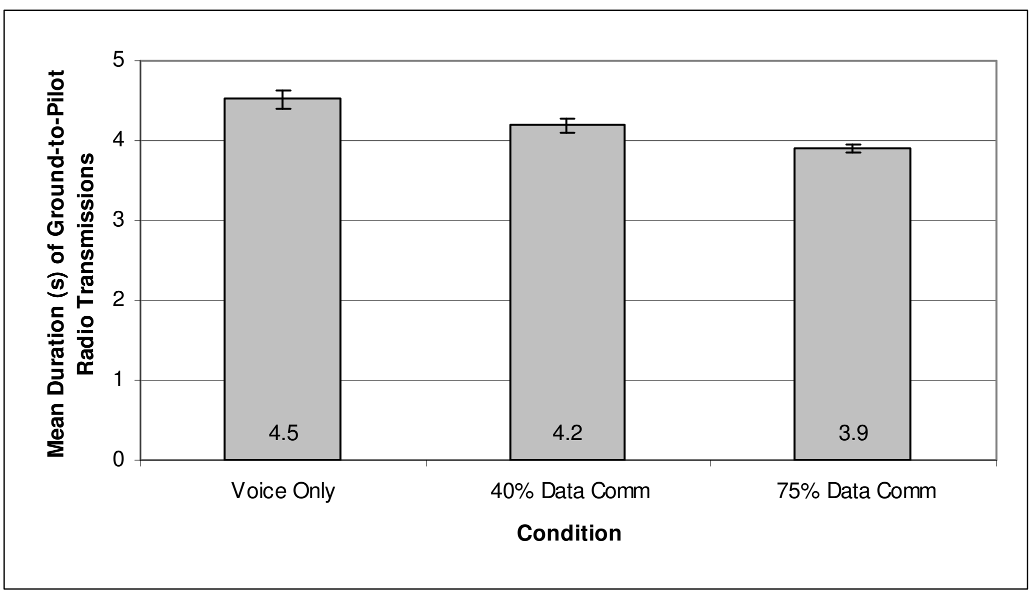

Figure 21. Mean duration of radio transmissions from the ground control position to the simulation pilots by condition.

The differences between the mean duration of radio transmissions from the participant at the ground control position to the simulation pilots were relatively small, especially between the Voice Only and 40% Data Comm conditions (0.3 s) and between the 40% and 75% Data Comm conditions (0.4 s). The difference between the 75% Data Comm condition and the Voice Only condition is somewhat larger, and perhaps more operationally significant (1.6 s). Compared to the Voice Only condition, the 75% Data Comm condition saved the participants about 6 min of time on the radio frequency per hour (1.6 s x 150 transmissions = 240 s or 4 min per 40 min scenario).

3.2.2 Local Controller to Simulation Pilots

There was one outlier in the dataset for the number of radio transmissions from the participant at the local control position to the simulation pilots during Run 2 of the 40% Data Comm condition, $G = 2.23$, $p = .018$. There was no statistical difference between the number of radio transmissions made from the participant at the local control position to the simulation pilots in the Voice Only ($M = 228.56$, $SD = 27.85$), 40% Data Comm ($M = 220.65$, $SD = 17.58$), and 75% Data Comm ($M = 226.00$, $SD = 26.75$) conditions.

We found a significant main effect of Run Number, evidence of a learning effect, for the duration of radio transmissions between the participant at the local control position and the simulation pilots. The participant at the local control position made shorter radio transmissions on average during Run 2 ($M = 3.63$ s, $SD = 0.82$) compared to during Run 1 ($M = 3.83$ s, $SD = 0.81$), $F(2, 14) = 12.04$, $p = .010$, *partial* $\eta^2 = .63$. The mean difference between Run 1 and Run 2 was 0.2 s. Condition did not affect the duration of radio transmissions between the participant at the local control position and the simulation pilots.

3.2.3 Simulation Pilots to Ground Controller

There was a significant effect of Condition on the number of radio transmissions from the simulation pilots to the ground control position, $F(2, 30) = 0.88$, $p < .001$, *partial* $\eta^2 = .42$. The simulation pilots made fewer radio transmissions to the ground control position in the 75% Data Comm condition compared to the Voice Only condition and the 40% Data Comm condition, $HSD(30) = 17.33$, $p < .001$ and $p = .022$, respectively (see Figure 22). There was no difference between the number of radio transmissions made in the Voice Only and the 40% Data Comm conditions.

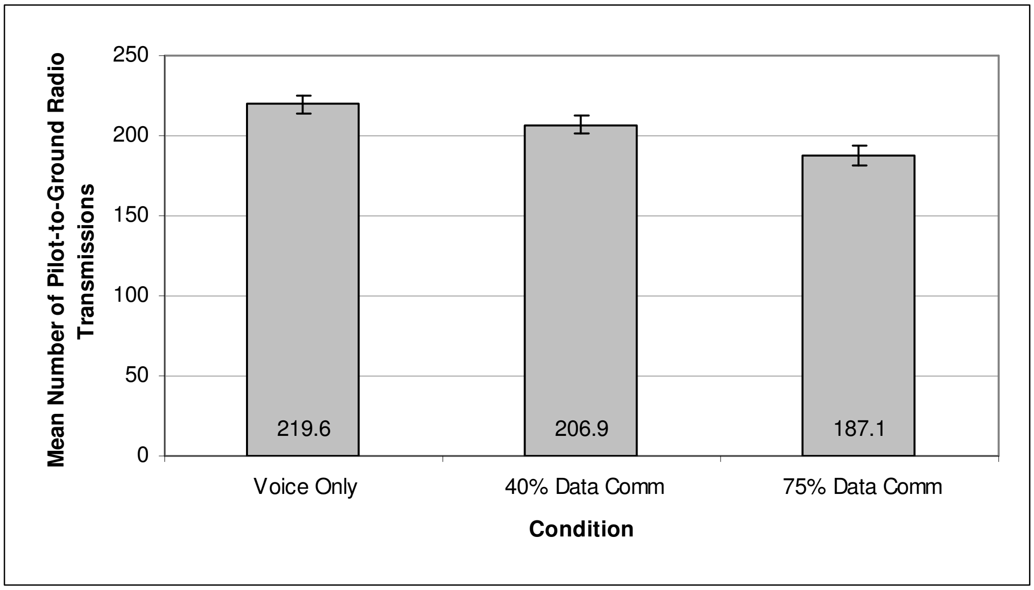

Figure 22. Mean number of radio transmissions from the simulation pilots to the ground control position by condition.

There was a significant effect of Condition on the duration of radio transmissions from the simulation pilots to the ground control position, $F(2, 30) = 9.25$, $p < .001$, *partial* $\eta^2 = .38$ (see Figure 23). Radio transmissions were shorter on average in the 75% Data Comm condition compared to the Voice Only condition and the 40% Data Comm condition, $HSD(30) = .16$, $p < .001$ and $p = .019$, respectively.

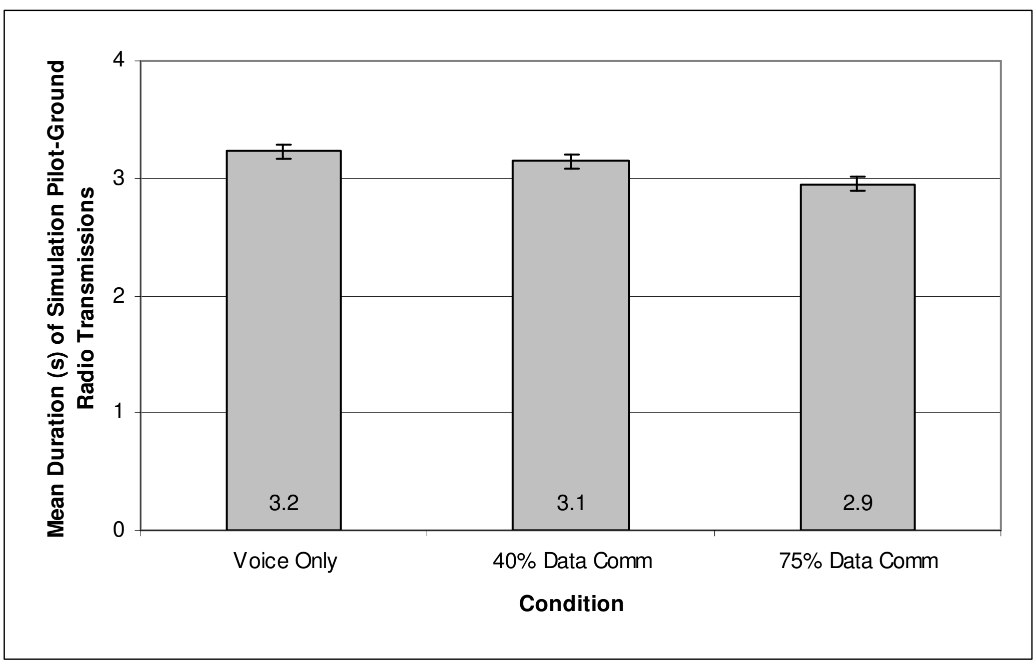

Figure 23. Mean duration of radio transmissions from the simulation pilots to the ground control position by condition.

Although these differences are relatively small, they may become operationally significant over time. The simulation pilots reduced their time on the radio frequency by about 1.5 min per hour when 75% of the aircraft were data link equipped compared to the Voice Only condition (0.3 s x 200 transmissions = 1 min per 40 min scenario).

3.2.4 Simulation Pilots to Local Controller

There was one outlier in the dataset for the number of radio transmissions from the simulation pilots to the participant at the local control position during Run 2 of the 40% Data Comm condition, $G = 2.14$, $p = .045$. There was no statistical difference between the number of radio transmissions made from the simulation pilots to the participant at the local control position in the Voice Only ($M = 267.06$, $SD = 26.35$), 40% Data Comm ($M = 268.16$, $SD = 18.05$), and 75% Data Comm ($M = 269.19$, $SD = 24.53$) conditions.

There was one outlier in the dataset for the duration of radio transmissions from the simulation pilots to the local control position during Run 2 of the 75%% Data Comm condition, $G = 2.43$, $p < .001$. There was a main effect of Condition on the duration of radio transmissions from the simulation pilots to the local control position, $F(2, 30) = 5.34$, $p = .010$, *partial* $\eta^2 = .26$ (see Figure 24). The simulation pilots made shorter radio transmissions in the 40% Data Comm condition compared to the Voice Only condition, $HSD(30) = .09$, $p = .008$.

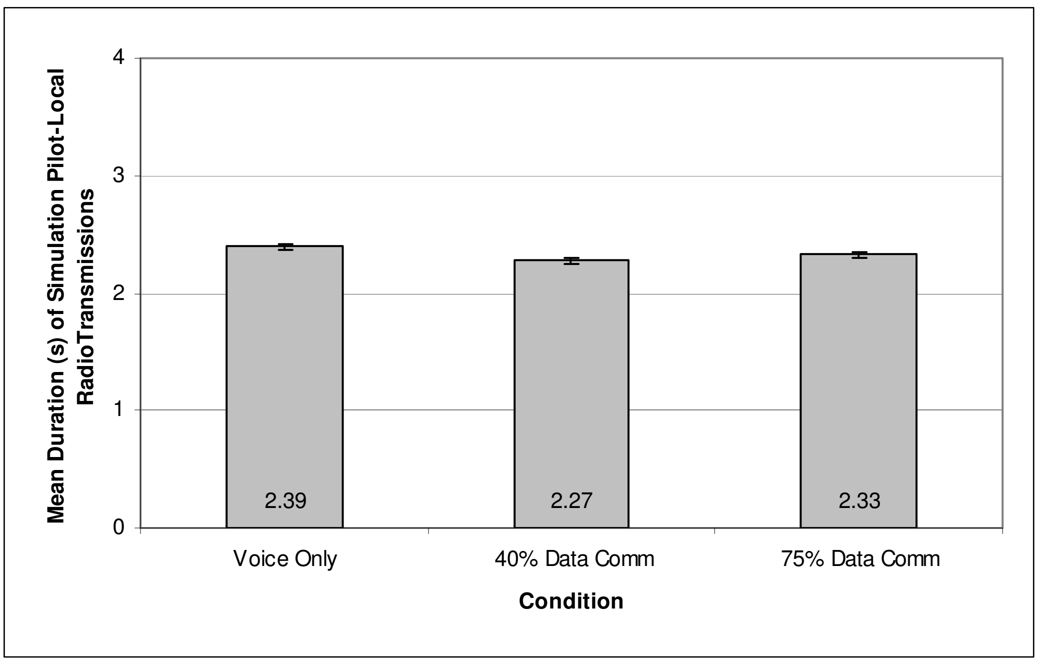

Figure 24. Mean duration of radio transmissions from the simulation pilots to the local control position by condition.

Again, the actual difference between the 40% Data Comm condition and the Voice Only condition was relatively small (0.12 s), but this reduction in the time on the radio frequency equated to about 50 s per hour (0.12 x 280 = 33.6 s per 40 min scenario).

3.3 Subjective Rating of Workload

We used the WAK to collect the participants' subjective ratings of their workload. The WAK measure, based on the research of Stein (1985), used a 10-button keypad to assess each participant's workload. If a participant did not respond to a WAK prompt within 20 s, we coded the response as missing data. Missing WAK data could have been the result of the participant not hearing or seeing the WAK prompt, or being too busy to respond. We did not assign the maximum rating of 10 to a missed WAK rating because we were unable to determine why the participant did not respond. Instead, we replaced missing WAK data with the Condition and Interval cell mean to afford statistical analyses. Of the 384 potential WAK ratings (3 Conditions x 8 Intervals x 16 participants), there were 28 missing observations for the ground control position (7.29%) and 49 missing observations for the local control position (12.76%). The missing data were distributed randomly across Condition and Interval. We examined the WAK data using a 3 (Condition) x 8 (Interval) repeated measures ANOVA.

When the participants worked at the ground control position, there was a significant main effect of Interval, $F(7, 105) = 21.36$, $p < .001$, *partial* $\eta^2 = .59$, showing that the participants' WAK ratings changed over time (see Figure 25). The post hoc test showed that there was a significant increase, $HSD(105) = 1.62$, in WAK ratings between the first and second intervals (5 min vs. 10 min), $p < .001$. The WAK ratings at the ground control position remained stable until the fifth interval (25 min) when the WAK ratings began to decrease compared to the second interval (10 min), $p = .007$. The WAK ratings continued to decrease until the final interval at the end of the scenario where the participants rated their workload as being lower than the first interval (5 min), $p < .001$.

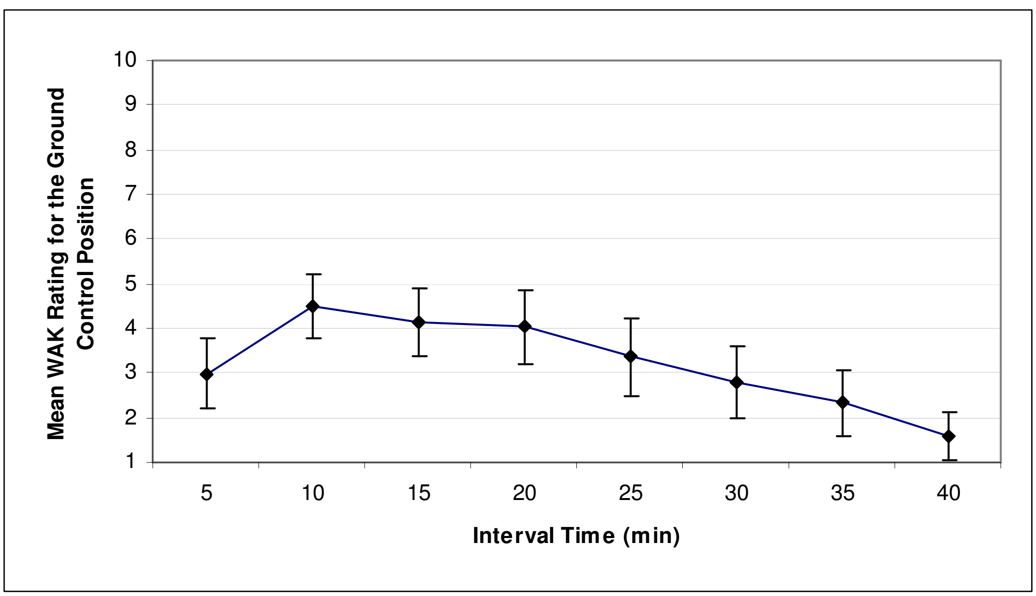

Figure 25. Mean WAK ratings for the ground control position by interval.

The participants' WAK ratings at the ground control position showed that their perception of workload changed over the course of each scenario, but they did not perceive a difference in the workload between the Voice Only (M = 3.22, SD = 4.11), 40% Data Comm (M = 3.07, SD = 4.67), and 75% Data Comm (M = 3.34, SD = 4.66) conditions. Either the D-Taxi operations generated as much workload as voice communications or the participants reallocated the cognitive and physical resources needed for voice communications to other tasks, including the D-Taxi processes.

There was also a significant main effect of Interval when the participants worked at the local control position, $F(7, 105) = 7.77$, $p < .001$, *partial* $\eta^2 = .34$ (see Figure 26). The post hoc test showed that the participants' WAK ratings for the local control position increased from the first interval (5 min) to the third interval (15 min), $HSD(105) = 1.56$, $p = .050$, and then the WAK ratings remained stable until the eighth interval (40 min) where they decreased, $p < .001$.

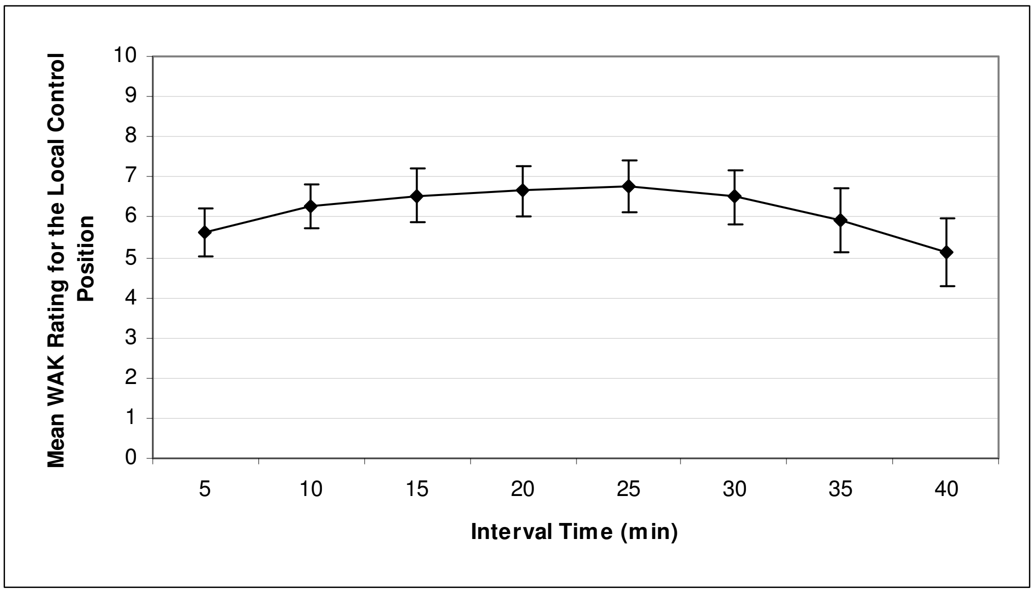

Figure 26. Mean WAK ratings for the local control position by interval.

Similar to the WAK ratings for the ground control position, the participants' WAK ratings for the local control position changed over the course of each scenario, but they did not perceive a difference in the workload between the Voice Only (M = 6.11, SD = 4.00), 40% Data Comm (M = 6.14, SD = 4.28), and 75% Data Comm (M = 6.26, SD = 3.73) conditions. There was no reason to hypothesize that the levels of Data Comm equipage would affect the participants' workload at the local control position. In fact, we did not detect any such effect of Condition.

3.4 Point of Gaze

We used video analysis software to determine where the participant at the ground control position was looking during each experimental scenario. We determined the number of looks and duration of each look at objects including the TODDS, OTW, WAK, and local control position. We also included a category for miscellaneous looks. We calculated the mean number of looks and the number of looks per minute for each object. This type of analysis, referred to as

Area of Interest (AOI) analysis, has the advantage of being easy and cost effective (David, 1985). Numerous studies have used AOI analysis to examine an operator's gaze in a number of environments, including truck drivers (McKnight, Shinar, & Hilburn, 1991), automobile drivers (Rahimi, Briggs, & Thom, 1990), pilots (Diez et al., 2001), power plant operators (Andersen & Hauland, 2000), and en route air traffic controllers (Cabon, Farbos, & Mollard, 2000; Hilburn & Nijhuis, 2000).

For the total number of looks by Condition and Object, the Grubbs test identified five outliers. Cells that contained outliers were for the (a) Voice Only condition, Miscellaneous object, G = 3.26, $p < .001$; (b) 40% Data Comm condition, Miscellaneous object, G = 3.68, $p < .001$; (c) 75% Data Comm condition, WAK object, G = 3.29, $p < .001$; (d) 75% Data Comm condition, Local Control Position object, G = 3.24, $p < .001$; and (e) 75% Data Comm condition, Miscellaneous object, G = 3.70, $p < .001$.

We conducted a 3 (Condition) x 5 (Object) repeated measures ANOVA on the total number of looks, and there was a significant main effect of Object, $F(4, 60) = 64.60$, $p < .001$, *partial* η^2 = .81. The post hoc analysis showed that the participants looked at the TODDS (M = 190.96, SD = 36.91) and the OTW view (M = 179.33, SD = 39.02) significantly more times than at the other objects, $HSD(60) = 117.99$, all $p < .001$. The participants looked at the WAK (M = 7.58, SD = 0.23), Local control position (M = 11.05, SD = 2.68), and Miscellaneous objects (M = 4.67, SD = 1.05) less often. Even though the participants used the D-Taxi functions of TODDS in the 40% and 75% Data Comm conditions, the participants made the same number of looks at the TODDS and OTW in the Data Comm conditions compared to the Voice Only condition (see Figure 27).

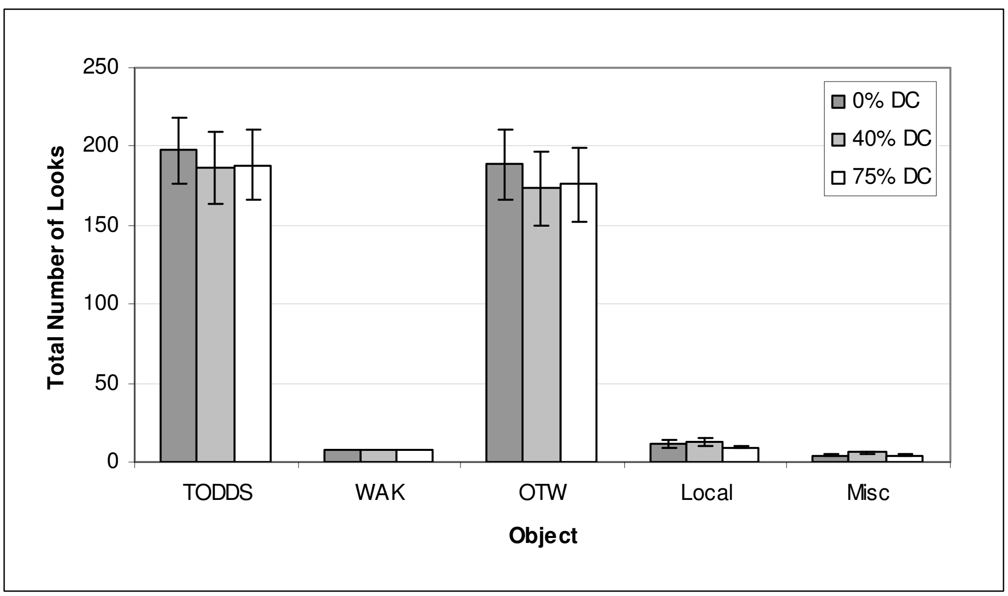

Figure 27. Total number of looks by condition and object at the ground control position.

For the total duration of looks, the Grubbs test identified five outliers. Cells that contained outliers were for the (a) Voice Only condition, Miscellaneous object, $G = 2.69$, $p = .028$; (b) 40% Data Comm condition, Local controller position object, $G = 2.86$, $p = .009$; (c) 40% Data Comm condition, Miscellaneous object, $G = 3.45$, $p < .001$; (d) 75% Data Comm condition, Local controller position object, $G = 3.34$, $p < .001$; and (e) 75% Data Comm condition, Miscellaneous object, $G = 3.55$, $p < .001$.

The 3 (Condition) x 5 (Object) repeated measures ANOVA on the total duration of looks identified a significant main effect of Object, $F(4, 60) = 298.63$, $p < .001$, *partial* $\eta^2 = .95$ (see Figure 28). The post hoc analysis showed that the participants looked at the TODDS longer than at any other object, $HSD(60) = 444.52$, $p < .001$, and they looked at the OTW view significantly longer than they looked at the WAK, Local control position, and Miscellaneous objects, all $p < .001$.

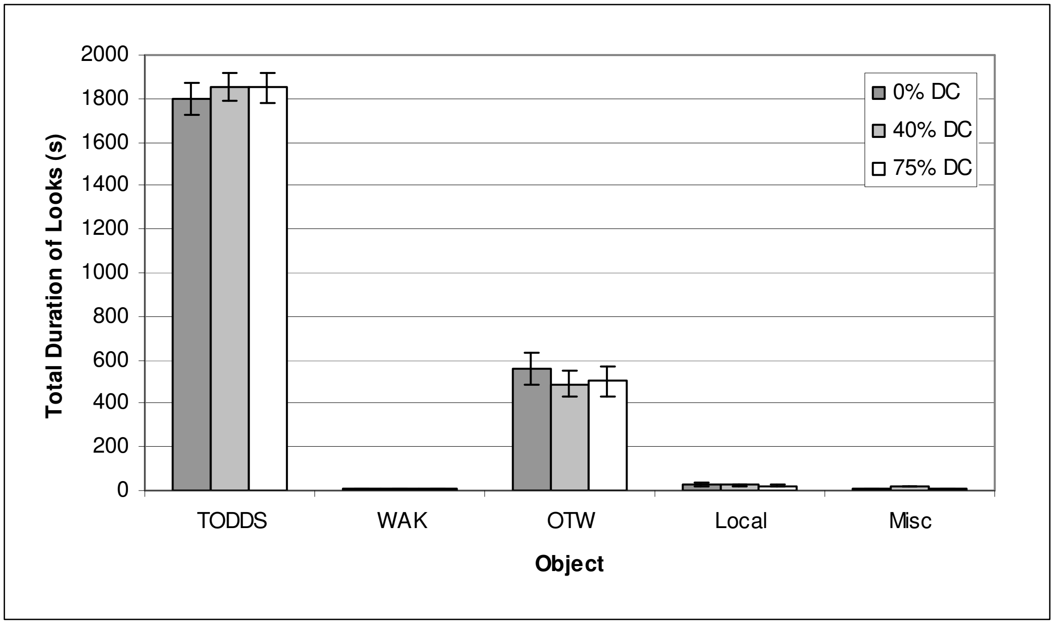

Figure 28. Total duration of looks by condition and object at the ground control position.

When the participants worked at the ground control position, they looked at TODDS for 30 min and 35 s ($M = 1835.01$ s, $SD = 112.36$) and at the OTW view for 8 min and 37 s ($M = 517.33$ s, $SD = 110.89$) of the 40 min scenario. The participants spent the remaining 48 s by dividing their visual attention between the WAK ($M = 11.23$ s, $SD = 1.16$), Local control position ($M = 23.63$ s, $SD = 6.07$), and Miscellaneous objects ($M = 13.16$ s, $SD = 2.75$).

Even though the participants used the D-Taxi functions of TODDS in the 40% and 75% Data Comm conditions, they spent the same amount of time looking at the TODDS and OTW in the Data Comm conditions compared to the Voice Only condition.

To better understand how often the participants were shifting their visual attention, we calculated the mean number of looks per minute by dividing the total number of looks for each object by 40 min (the duration of each scenario). There were five outliers in the dataset: (a) Voice Only, Miscellaneous object, $G = 3.24$, $p < .001$; (b) 40% Data Comm, Miscellaneous object, $G = 3.68$, $p < .001$; (c) 75% Data Comm, WAK object, $G = 3.22$, $p < .001$; (d) 75% Data Comm, Local object, $G = 3.25$, $p < .001$; and (e) 75% Data Comm, Miscellaneous object, $G = 3.70$, $p < .001$. There was a main effect of Object, $F(4, 60) = 64.39$, $p < .001$, *partial* $\eta^2 = .81$ (see Figure 29), showing that the participants most often shifted their visual attention between TODDS and OTW. The participants shifted their visual attention to the TODDS and the OTW view over four times per minute.

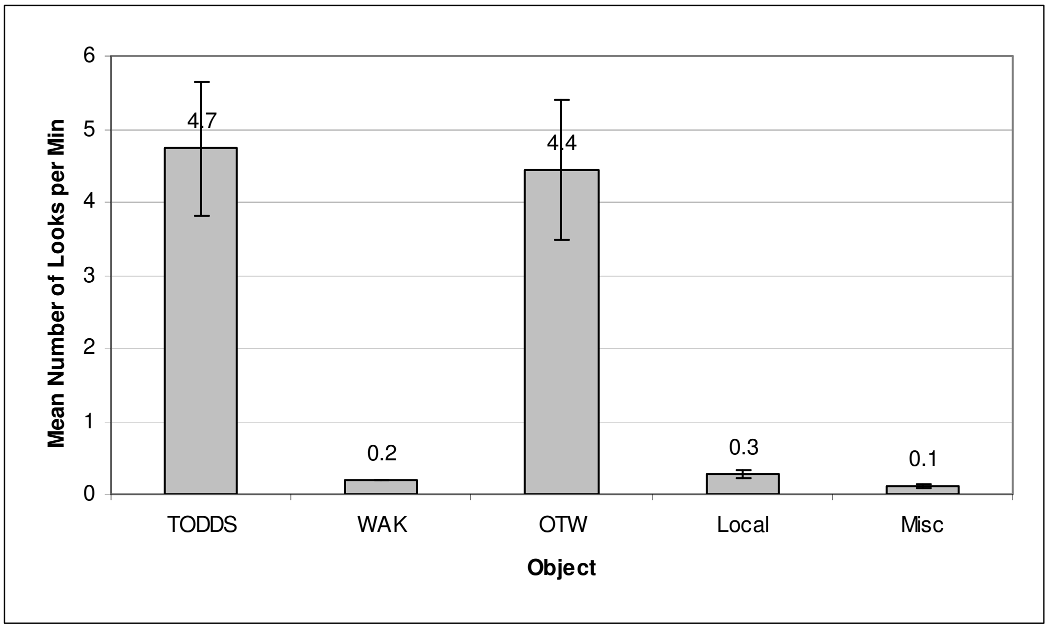

Figure 29. Mean number of looks per minute by object at the ground control position.

We calculated the mean duration of looks for each object by dividing the total duration of looks by the total number of looks. There were seven outliers in the dataset: (a) Voice Only, Miscellaneous object, $G = 2.93$, $p = .006$; (b) 40% Data Comm, TODDS object, $G = 2.44$, $p < .001$; (c) 40% Data Comm, OTW object, $G = 2.65$, $p = .035$; (d) 40% Data Comm, Local control position object, $G = 3.43$, $p < .001$; (e) 40% Data Comm, Miscellaneous object, $G = 3.40$, $p < .001$; (f) 75% Data Comm, TODDS object, $G = 3.39$, $p < .001$; and (g) 75% Data Comm, Miscellaneous object, $G = 2.36$, $p = .025$.

The 3 (Condition) x 5 (Object) repeated measures ANOVA showed a significant main effect of Object, $F(4, 60) = 27.08$, $p < .001$, *partial* $\eta^2 = .64$ (see Figure 30). When the participants looked at the TODDS, their looks were significantly longer than when they looked at any other object, $HSD(60) = 7.77$, all $p < .001$. The mean duration of the participants' looks did not differ when they looked at the WAK, OTW, Local control position, or Miscellaneous objects. The mean duration of looks did not differ between the Voice Only ($M = 4.09$ s, $SD = 2.10$), 40% Data Comm ($M = 4.20$ s, $SD = 1.99$), and 75% Data Comm ($M = 4.09$ s, $SD = 2.41$) conditions. The participants increased the mean duration of their looks at TODDS by about 1 s in the 40% Data Comm (M = 11.80 s, SD = 1.72) and 75% Data Comm (M = 11.90 s, SD = 2.02) conditions compared to the Voice Only (M = 10.76 s, SD = 1.79) condition. Although this difference was not significant, it may be attributed to the use of D-Taxi clearances, which took the participants about 1 s to complete.

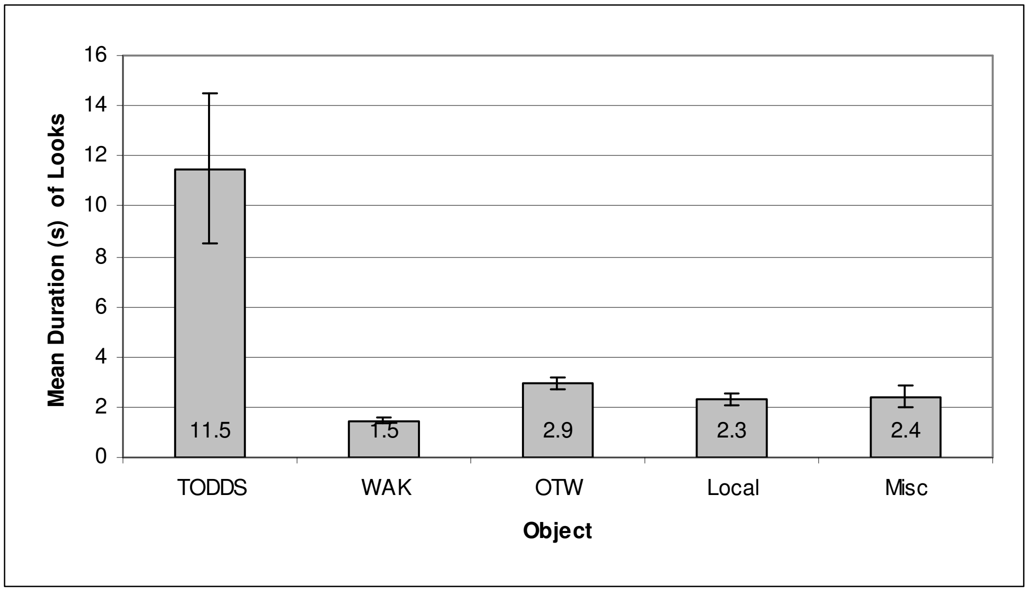

Figure 30. Mean duration of looks by object at the ground control position.

3.5 Operational Error Data

An SME monitored each scenario on a traffic situation display at the TGF operator's workstation. The SME had a full view of all aircraft on the ramp area, taxiways, runways, and in the surrounding airspace. The SME could monitor aircraft operational variables (e.g., altitude and airspeed) as well as all simulation pilot commands. The SME noted instances of operational errors or deviations and coded six types of errors (Figure 31 shows the mean number of errors by Condition and Type).

1. An Arrival-Departure (AD) error occurred when there was a loss of minimum separation (horizontal and vertical) between an arrival and a departure aircraft either on the same runway or on different runways.
2. A Wake Turbulence (WT) error occurred when aircraft separation exceeded the minimum horizontal distance and time required for WT spacing.
3. The SME recorded a Land Over (LO) whenever an aircraft landed over another aircraft that was holding in position on the runway or otherwise on the same runway.
4. An Arrival-Arrival (AA) error occurred when two arrival aircraft lost minimum separation distance.

5. A Departure-Departure (DD) error occurred whenever two departure aircraft lost minimum separation distance.
6. A Runway Incursion (RI) was recorded whenever an aircraft was crossing, occupying, or otherwise obstructing the runway during a takeoff or landing operation on the same or an intersecting runway.

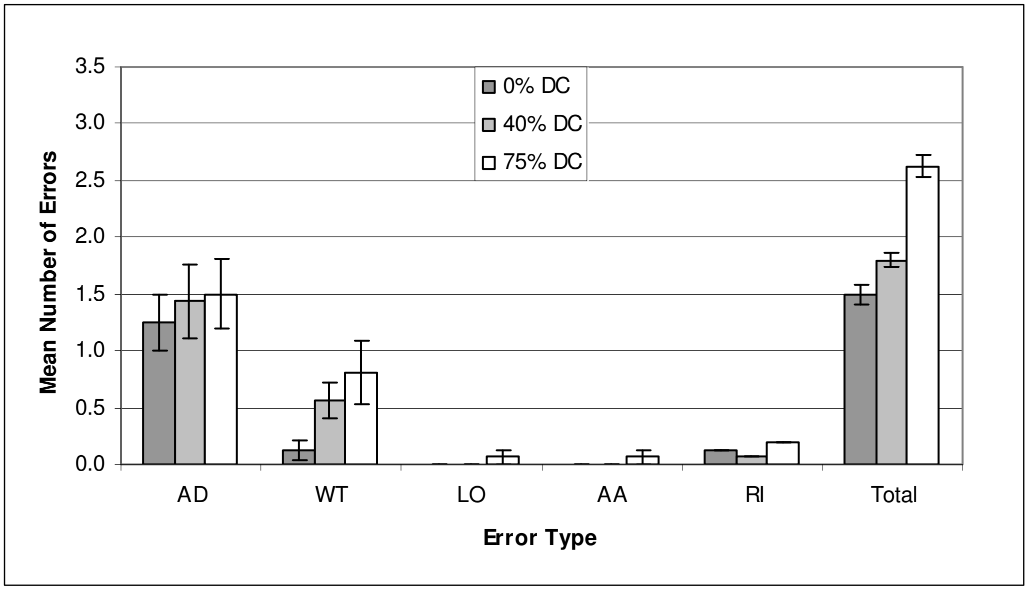

Figure 31. Mean number of errors by condition and error type.

The participants did not make any DD type errors. We analyzed the total number of errors using a one-way repeated measures ANOVA. A significant main effect of Condition, $F(2, 30) = 4.19$, $p = .025$, *partial* $\eta^2 = .22$, showed (along with the post hoc test) that the participants made significantly fewer errors in the Voice Only condition compared to the 75% Data Comm condition, $HSD(30) = 1.41$, $p = .024$. This is a relatively small effect. It is difficult to determine why Data Comm, and in particular D-Taxi clearances for departure aircraft, would increase the number of errors made primarily by the local controller. Of the RIs that occurred in the Data Comm conditions, the SME did not attribute any of these to a D-Taxi clearance.

3.6 D-Taxi Usability

We collected objective and subjective usability measures for TODDS. The usability measures helped us to identify any D-Taxi features that were difficult to use, and allowed the participants to provide suggestions for changes and new features. We recorded the number and types of actions the participants performed with TODDS during each scenario. We then calculated an error rate (ER) for each action type by dividing the number of failed actions (F) by the sum of successful actions (S) and failed actions (F), so that ER = F/(S+F). The participants provided subjective usability data by completing the questionnaires.

The overall error rate for the ground control position of TODDS was 3.3% across all experimental and exploratory scenarios. The error rate for issuing a D-Taxi clearance was 7.6% (80 misses out of 969 attempts). The ability to move the D-Taxi button was the largest contributor to the error rate for D-Taxi clearances. The participant could either select the D-Taxi button to issue a D-Taxi clearance or drag the D-Taxi button to move it to a new location. If the user moved the D-Taxi button while selecting it, the TODDS registered the action as a drag instead of a selection and TODDS did not issue the D-Taxi clearance. We could reduce a large number of these errors by limiting the amount of movement allowed for buttons, including the D-Taxi button. The participants rarely canceled a D-Taxi clearance ($n = 12$) or edited a D-Taxi route ($n = 5$), and they never added or removed a hold short point from a D-Taxi clearance. The participants provided additional insight into the usability of TODDS in general and D-Taxi in particular by responding to the PSQ and PEQ.

Despite the number of errors, the participants were able to construct and issue D-Taxi clearances very rapidly. It took the participants slightly longer to issue a D-Taxi clearance in the 40% Data Comm condition ($M = 1.38$ s, $SD = .62$) than in the 75% Data Comm condition ($M = 1.18$ s, $SD = .51$), $F(1, 15) = 5.28$, $p = .036$, *partial* $\eta^2 = .26$. Although this effect was relatively small, it is not clear why the time to construct and issue D-Taxi clearances differed between the two conditions. There was no evidence of a learning effect between runs. Overall, the participants were able to construct and issue a D-Taxi clearance in only 1.28 s on average, including the time consumed by usability errors.

3.7 Post-Scenario Questionnaire

The participants completed the PSQ (see Appendix F) after each data collection scenario. Items 1 through 6 concerned Data Comm, and the participants did not respond to these items after working in the Voice Only condition (or if they worked at the local control position). The participants also did not respond to Item 7 after working at the local control position because that item concerned taxi clearances. The participants provided their responses using a Likert scale rating ranging from 1 (*extremely low*) to 10 (*extremely high*). We analyzed each item of the PSQ separately for both the ground and local controller positions, and there were no significant differences between the Voice Only, 40% Data Comm, and 75% Data Comm conditions on any of the items. Table 7 presents the mean responses for each PSQ item by controller position and Condition.

Table 7. Means (*M*) and Standard Deviations (*SD*) of Responses for Each Item of the PSQ by Controller Position and Condition

Item	**Condition**	**Ground**	**Local**
		***M* (*SD*)**	***M* (*SD*)**
1 - Rate the effort needed to recognize the aircraft that were Data Comm equipped.	40%	3.00 (2.32)	N/A
	75%	2.06 (1.89)	N/A
2 - Rate the effort needed to recognize a request for a D-Taxi clearance.	40%	2.63 (1.54)	N/A
	75%	2.63 (2.47)	N/A
3 - Rate your ability to recognize an acknowledged D-Taxi clearance.	40%	7.31 (2.75)	N/A
	75%	7.25 (3.15)	N/A
4 - Rate your ability to recognize a failed D-Taxi clearance.	40%	7.13 (2.91)	N/A
	75%	7.81 (3.03)	N/A
5 - Rate the effort needed to issue a canned D-Taxi clearance.	40%	2.13 (1.96)	N/A
	75%	2.19 (2.14)	N/A
6 - Rate the effort needed to issue a user-defined D-Taxi clearance.	40%	3.08 (2.57)	N/A
	75%	2.38 (1.89)	N/A
7 - Rate the effort needed to issue a taxi clearance via voice.	Voice	3.77 (2.45)	N/A
	40%	2.69 (1.34)	N/A
	75%	3.23 (2.33)	N/A
8 - Rate the effort needed to maintain flight data.	Voice	3.63 (2.05)	4.94 (2.75)
	40%	3.50 (2.13)	3.75 (1.98)
	75%	3.69 (2.26)	4.63 (2.18)
9 - Rate your ability to find necessary flight information.	Voice	2.88 (1.73)	3.75 (1.89)
	40%	3.13 (1.45)	4.06 (2.01)
	75%	2.81 (1.67)	4.38 (2.18)

(*Table continues*)

Item	Condition	Ground	Local
		***M* (*SD*)**	***M* (*SD*)**
10 - Rate your ability to find necessary weather information.	Voice	2.06 (1.20)	2.13 (1.22)
	40%	2.13 (1.27)	2.06 (1.30)
	75%	1.75 (0.97)	1.94 (1.25)
11 - Rate the effort needed to transfer flight data.	Voice	2.69 (1.57)	4.88 (2.12)
	40%	2.88 (1.65)	4.44 (2.18)
	75%	3.06 (1.56)	4.88 (2.09)
12 - Rate your ability to detect aircraft on the runway.	Voice	7.53 (2.07)	6.94 (2.25)
	40%	8.60 (1.06)	7.50 (2.44)
	75%	8.40 (1.99)	7.69 (2.10)
13 - Rate your awareness for current aircraft locations.	Voice	7.67 (1.93)	7.13 (1.61)
	40%	7.80 (1.56)	7.33 (1.88)
	75%	8.40 (1.06)	7.20 (1.45)
14 - Rate your awareness for projected aircraft locations.	Voice	7.27 (2.10)	7.13 (1.42)
	40%	8.13 (1.97)	7.69 (1.54)
	75%	8.47 (0.89)	7.56 (1.45)
15 - Rate your awareness for potential runway incursions.	Voice	7.60 (1.58)	7.13 (1.68)
	40%	8.07 (1.37)	7.38 (1.54)
	75%	8.00 (1.82)	7.44 (1.32)
16 - Rate your awareness of the overall traffic situation.	Voice	8.27 (1.14)	7.06 (1.19)
	40%	8.13 (1.35)	7.06 (1.56)
	75%	8.07 (1.24)	6.88 (1.98)
17 - Rate your workload due to controller-pilot communication.	Voice	5.87 (1.88)	6.00 (2.12)
	40%	4.73 (1.96)	5.75 (1.90)
	75%	4.20 (2.01)	5.69 (1.47)
18 - Rate your overall workload.	Voice	6.20 (1.63)	7.50 (1.09)
	40%	5.07 (2.01)	7.50 (1.48)
	75%	5.33 (1.87)	7.75 (1.27)
19 - Rate the safety of operations.	Voice	8.07 (1.53)	6.20 (1.38)
	40%	8.40 (1.26)	6.33 (1.82)
	75%	8.20 (1.13)	6.80 (1.18)
20 - Rate the necessity of coordination between the ground and local positions.	Voice	3.07 (1.19)	3.44 (1.57)
	40%	3.73 (1.49)	3.63 (1.74)
	75%	4.53 (2.43)	3.69 (1.91)

In addition to the Likert scale ratings, the participants wrote down comments that they had relating to each of the PSQ Items (see Appendix I). The participants were able to recognize both acknowledged and failed D-Taxi clearances very well. When the participants worked at the ground control position, they reported that it took very little effort to recognize which aircraft were Data Comm equipped and to recognize a pilot request for a D-Taxi clearance.

There was one aircraft in every scenario that had a D-Taxi failure (i.e., Data Comm indicator turned red and D-Taxi did not function). Although one participant thought the failed Data Comm indicator was too subtle ("I like the red, but it needs to stand out a little more"), other participants thought the symbol was "very usable." They reported that it took little effort to issue either a canned or a user-defined D-Taxi clearance.

The participants reported that it was easy to manage flight data. They had a high awareness of current and projected aircraft positions, potential runway incursions, and the overall traffic situation. Workload due to controller-pilot communications was moderate as was overall workload, but workload at the local control position was slightly higher than workload at the ground control position. The participants rated the safety of operations at the ground control position as high, but they thought it was less safe at the local control position. It is likely that the participants had some concerns about the safety at the local control position because of the complex, busy traffic scenarios that included arrivals and departures on intersecting runways. The necessity for coordination between the ground and local control positions was low because coordination was only required when the ground controller had to taxi 33R arrivals across runway 33L before sending them to the ramp.

3.8 Exploratory Scenarios

The participants worked in two 30-min exploratory scenarios at the end of the experiment. They worked one scenario each from the ground and local control positions. During each exploratory scenario, there was a total Data Comm failure that lasted for 10 min. The participants were able to handle the Data Comm failure very easily. When they noticed that Data Comm was not functioning, they simply reverted to issuing voice clearances just as they do in the real world today. They immediately resumed using the D-Taxi Data Comm feature as soon as it became available again.

During the exploratory scenarios, the participants also experienced two aircraft that did not conform to their taxi clearances. The participant at the ground control position had given one of the nonconforming aircraft a taxi clearance by voice; the other aircraft had a D-Taxi clearance. The participants noticed the nonconforming aircraft, regardless of clearance type, almost as soon as the pilot made an errant turn on the taxiway. There was only one instance when the participant did not notice an aircraft that did not conform to a taxi clearance. In that instance, the participant had issued the taxi clearance by voice.

3.9 Post-Experiment Questionnaire

After the participants completed all of the practice, experimental, and exploratory scenarios, they provided Likert scale and open-ended responses to the PEQ; see Appendix J. The participants provided their responses using a Likert scale rating ranging from 1 (*extremely low*) to 10 (*extremely high*). For the PEQ items numbered 6 and 17, the participants used a Likert scale rating where a rating of 1 indicated a *negative effect*, a rating of 5 indicated *no effect*, and a rating of 9 indicated a *positive effect* (see Table 8).

Table 8. Means (*M*) and Standard Deviations (*SD*) of Responses for Each Item of the PEQ

Item	*M* (*SD*)
1 - Rate the readability of the readout area on the TODDS.	8.50 (1.41)
2 - Rate the readability of the weather information box on the TODDS.	8.00 (1.46)
3 - Rate the readability of the flight data elements on the TODDS.	7.13 (2.83)
4 - Rate the readability of the data blocks on TODDS.	7.38 (2.90)
5 - Rate the overall effort needed to use the touchscreen when using the TODDS.	4.44 (2.00)
6 - What effect do you think D-Taxi will have on your ability to control traffic in the tower?	8.25 (0.93)
7 - Rate the effort needed to manage a complete Data Comm failure.	3.50 (1.83)
8 - Rate the effort needed to detect an aircraft that deviated from a taxi clearance that was issued via voice.	4.31 (2.30)
9 - Rate the effort needed to detect an aircraft that deviated from a taxi clearance that was issued via D-Taxi.	2.44 (1.09)
10 - Rate the effort needed to manage an aircraft that deviated from a taxi clearance that was issued via voice.	4.06 (2.02)
11 - Rate the effort needed to manage an aircraft that deviated from a taxi clearance that was issued via D-Taxi.	3.69 (1.70)
12 - Rate how useful D-Taxi would be for taxi-in operations.	7.00 (2.62)
17 - What effect do you think TODDS will have on your ability to control traffic in the tower?	7.38 (1.50)

Overall, the participants rated the readability of TODDS as *high*. They thought that even though it required some effort to use the touchscreen, the effort was still relatively *low*. The participants thought that D-Taxi would have a positive effect on their ability to control airport traffic. The participants commented that it required low effort to manage the complete data link failure. We conducted planned comparisons on Items 8 and 9 and Items 10 and 11 to see if the participants perceived a difference in the level of effort required to detect and manage aircraft that had deviated from their assigned taxi route when they used D-Taxi versus voice. The participants rated the effort to give a voice clearance (PEQ Item 8) as being higher than the effort to give a D-Taxi clearance (Item 9), $t(15) = 3.58$, $p = .003$. The participants did not perceive a difference in the effort needed to manage an aircraft that deviated from its taxi clearance, given the type of taxi clearance (voice vs. D-Taxi).

Some of the participants thought that D-Taxi may be useful for taxi-in operations, but they did not elaborate on a particular set of procedures that would be likely to work, and we did not have time during the debriefing to generate such a set of procedures. Other participants said that D-Taxi for arrivals would be "more challenging" and could result in blocked runway exits and increased pilot workload. The participants thought that the TODDS, as an overall system including D-Taxi, would have a positive effect on the ability to control airport traffic. Items 13-16 of the PEQ asked the participants about D-Taxi in particular. Some of the participants stated that they would use D-Taxi as much as possible. However, others stated that they would not use D-Taxi during rapidly changing weather conditions, during low visibility conditions, during times that the pilot was unfamiliar with the airport, during times that an aircraft had an Expected Departure Clearance Time (EDCT), or during emergencies. Of course, the participants mentioned less voice communications as one of the greatest benefits of D-Taxi. They also mentioned the reduced risk of readback and hearback errors, greater situation awareness, and less confusion (especially with foreign pilots). Of the biggest problems with D-Taxi, there were few. Rather than focusing on D-Taxi, the participants mostly mentioned usability issues with the TODDS, in general, such as information clutter and selecting buttons on the touchscreen. When asked about additional D-Taxi features, the participants again made a number of comments regarding the general usability of TODDS. One participant recommended an additional D-Taxi feature that would allow the controller to add an instruction to hold short of a taxiway.

The PEQ Items 17-20 asked the participants about TODDS in particular. The participants thought that TODDS would have a positive effect on the ability to control traffic in the tower. They also said that TODDS had a learning curve that one must overcome before taking full advantage of the tool. The participants listed a number of benefits for TODDS, including the fact that TODDS integrates and makes available all of the most important information on a single screen. They thought that TODDS would work in low visibility conditions and that it would improve safety, reduce workload, and reduce the need for verbal communication and coordination.

When asked about the greatest problems with TODDS, the participants mentioned the same type of items that they listed for D-Taxi – primarily, datablock overlap and clutter. The usability issue of clutter was due primarily to the participants' lack of a strategy for manually arranging the datablocks and the limited amount of training that they received. Some of the participants simply let the TODDS automatic datablock offset algorithm separate the datablocks for them, but this resulted in a suboptimal arrangement and contributed to their perception of clutter even though there was no datablock overlap or crossed leader lines. Once the participants manually repositioned a datablock, the datablock was removed from the automatic offset algorithm and the datablock's leader line maintained its length and orientation; this can lead to datablock overlap. TODDS had a function that allowed the participants to place all or some of the datablocks back into the automatic offset algorithm and remedy any datablock overlap and crossed leader lines, but the participants rarely used this function. Some participants suggested that the TODDS hide datablocks during certain situations when flight data are transferred from one controller position to another.

The participants made many suggestions for changes or additions to TODDS, and the research team will consider all of their suggestions for implementation in future design iterations. One participant's comment was more related to D-Taxi as it suggested that controllers should have a means to show a D-Taxi route graphically after it has been issued and accepted. Others suggested a better delineation between FDEs on the local control position for aircraft going to different runways, an "H" designator for heavy aircraft, color coding for arrival aircraft, and aural alerts for taxiway conformance violations. We will consider all of the participants' suggestions during the next design iteration of TODDS. The complete set of participants' comments on the PEQ appears in Appendix J.

4. CONCLUSION

4.1 System Operations

The use of D-Taxi clearances did not affect the duration of taxi-in operations, the number or duration of delays, or the number of arrivals and departures. The use of D-Taxi clearances did, however, increase the duration that aircraft waited on the ramp before starting their taxi. This result was due to the D-Taxi procedure and the associated data link delays (i.e., LAK delay, pilot response). Compared to the Voice Only condition, aircraft waited on the ramp 16.2 s longer in the 40% Data Comm condition and 19.7 s longer in the 75% Data Comm condition. Increasing the level of data link equipage from 40% to 75% did not significantly increase the time that aircraft waited on the ramp before starting to taxi. The duration of taxi-out operations generally decreased with increasing levels of data link equipage, but this difference was not statistically significant because there was sufficient variability between the participants' performance at the local control position. Compared to the Voice Only condition, the average aircraft taxi-out duration decreased by 33.6 s in the 40% Data Comm condition, whereas the average aircraft taxi-out duration decreased by 52.1 s in the 75% Data Comm condition. Although the differences in taxi-out duration were not statistically significant, they may be operationally significant and could more than offset the additional time that aircraft waited on the ramp in the Data Comm conditions.

In a previous experiment, Truitt and Muldoon (2009) found similar results regarding ramp waiting and taxi-out durations. The participants used the TODDS to manage traffic scenarios that were identical to the scenarios used in the current experiment. As in the current study, they found that the duration that aircraft waited on the ramp when controllers had surface surveillance available was 25 s longer in the TODDS condition. They attributed this delay to the delays associated with digital communications. However, taxi-out durations were reduced by 94 s in the TODDS condition. Taken together, the results of the current experiment and of the prior experiment by Truitt and Muldoon suggest that while D-Taxi may result in longer ramp waiting times compared to voice communications, overall system efficiency may improve due to an operational reduction in the duration of taxi-out times that may offset any delays experienced on the ramp prior to the initial taxi movement.

Given the lack of an established or proposed set of procedures for D-Taxi, we implemented what we believed to be the best procedural solution for the use of D-Taxi clearances for departure aircraft. The pilots used the data link capability to request a taxi clearance once the aircraft reached a ramp spot. The ground controller then constructed and issued the D-Taxi clearance.

When the pilot received and accepted the clearance, the ground controller contacted the pilot on the voice radio frequency and instructed the pilot to begin to taxi. This procedure ensured a smooth transition from the ramp controller to the ground controller and from the nonmovement area (ramp) to the movement area. The procedure as implemented also provided a means for the ground controller to verify that voice communications were operational, and it maintained the ground controller's awareness and ability to determine the sequence and flow of all surface movements. It is likely the duration of taxi-out operations were reduced enough to compensate for the increase in ramp holding time because holding the aircraft on the ramp a little longer resulted in less congestion on the taxiways and afforded slightly more efficient taxi-out operations overall. Furthermore, although the TODDS used a form of automation that proposed a standard taxi route that could account for closed runways, taxiways, and taxiway segments, future automation may provide additional decision support tools to help the ground controller generate initial taxi times and determine a departure sequence. However, initial movement of an aircraft really begins with push back from the gate – such automation affects the ground controller indirectly at best. Therefore, as Jakobi et al. (2009) suggest, we recommend that the construction and issuance of D-Taxi clearances remain within the purview of the ground controller. However, it is important that future research examines ramp operations to determine whether increasing the duration that an aircraft waits on the ramp might impact nonmovement area operations.

4.2 Communications

The use of D-Taxi clearances did not affect the number of transmissions from the ground control position to the simulation pilots, the local control position to the pilots, or the pilots to the local control position. The simulation pilots made fewer transmissions to the ground control position in the 75% Data Comm condition compared to the Voice Only and 40% Data Comm conditions. The duration of transmissions from the ground control position to the simulation pilots became shorter as the level of data link equipage increased. Compared to the Voice Only condition, the ground controller saved about 6 min/hr on the frequency in the 75% Data Comm condition. The simulation pilots also made shorter radio transmissions in the 75% Data Comm condition compared to the Voice Only and 40% Data Comm conditions, saving about 1.5 min/hr on the frequency. Rakas and Yang (2007) warned that the inherent delays associated with Data Comm could lead to more miscommunications and additive delays in controller transmissions. The research team was unable to count the number of miscommunications that occurred, but we found that, overall, usage of the ground control frequency decreased by 7.5 min/hr or 12.5% when 75% of the departure aircraft received D-Taxi clearances compared to ground control frequency usage in the Voice Only condition. While D-Taxi may lead to longer transmission times and more open messages compared to voice communications, the use of data link communications should reduce the potential for miscommunication and errors due to incorrect pilot readbacks and controller hearbacks. D-Taxi also provides controllers with a means to review the clearances they have sent, rather than having to write them down or remember them.

4.3 Workload

Controller workload was unaffected by the use of D-Taxi clearances. Although the participants' WAK ratings changed between rating intervals, they did not vary between conditions. The participants rated the effort required to give a voice clearance as being higher than the effort required to give a D-Taxi clearance. The participants did not perceive a difference in the effort needed to manage an aircraft that deviated from its taxi clearance, given the type of taxi clearance (voice vs. D-Taxi).

4.4 Point of Gaze

The participants at the ground control position looked at the TODDS and OTW more often compared to looking at the WAK, Local control position, and Miscellaneous objects. The participants looked at the TODDS and OTW the same number of times, regardless of whether they used D-Taxi clearances or not. When the participants worked at the ground control position, they looked at TODDS for 30 min and 35 s (76.5% of the time), and they looked OTW for 8 min and 37 s (21.5% of the time) of the 40 min scenario. The participants spent the same amount of time looking either at the TODDS or OTW in all conditions, despite the fact that they had to construct and issue D-Taxi clearances via TODDS in the Data Comm conditions. When the participants looked at the TODDS, their looks were significantly longer than when they looked at any other object. The mean duration of all looks across all Conditions was about 4 s.

The amount of time that the participants spent looking at the TODDS may have been, in part, an artifact of the experiment because the participants were not as familiar with the TODDS as they would be if they were actually using such an integrated system in the field. In future experiments, researchers should maximize the participants' familiarity with any new system.

Although it may seem excessive that the participants spent 76.5% of their time looking at the TODDS and only 21.5% of their time looking OTW, previous studies provide some perspective. Bruce (1996) collected quantitative measurements of controller movements and actions to assess the suitability of the ATCT environment for employees with limited mobility. Researchers observed and recorded controller behavior at Austin Meuller, Memphis International, Milwaukee/ General Mitchell Field, Philadelphia International, San Francisco International, and Teterboro airports. When she conducted the study, only the Milwaukee, Philadelphia and San Francisco airports had surface surveillance capabilities in the form of ASDE. Bruce found that ground controllers spent about 50% of their time looking OTW, and they looked at the ASDE less than 1% of the time. The ASDE capabilities simply were not used much at that time and ground controllers did not look at the ASDE display very often. More recently, Hilburn (2004) conducted a HITL tower simulation to examine how an A-SMGCS affected controller heads-down time. The A-SMGCS is the European equivalent to the modern ASDE-X. Fifteen controllers from Roissy Charles de Gaulle and Orly airports served as participants. He found that the controllers spent only 12% of their time looking OTW, and 83% of their time heads-down looking at the A-SMGCS or flight progress strips. The findings of our current study are similar to those of Hilburn.

On the basis of these studies, one can surmise that the presence of an informative surface surveillance system can increase controller heads-down time. However, one cannot conclude that more heads-down time is detrimental. In fact, appropriately designed surface surveillance displays may provide more information in a faster and better way than simply looking OTW. Heads-down time can become even more valuable when the controller is looking at an integrated display that puts all of the most important information (surface surveillance, flight data, weather information, and D-Taxi functionality) on the same display directly within the controller's field of view. As recommended by Kerns (1991) and Metzger and Parasuraman (2006), such an integrated display reduces the need for controllers to constantly shift their visual attention between multiple information displays. New controller tools and information displays will necessarily increase heads-down time if they are difficult to use or if they provide useful information. Rather than trying to determine how much heads-down time is too much, we must ensure that any time used as heads-down is time well spent.

4.5 Participant Feedback

The participants thought that D-Taxi would have a positive effect on their ability to control airport traffic. The participants also said that it required very little effort to manage a complete data link failure. The participants thought that D-Taxi may be useful for taxi-in operations, even though it was not clear what procedures would be used. They thought that the TODDS as an overall system, including D-Taxi, would have a positive effect on the ability to control airport traffic. The participants said that it required some effort to use the touchscreen, but the effort was relatively low.

5. FUTURE RESEARCH

To ensure the ecological validity of all future research regarding Data Comm and D-Taxi operations in the ATCT environment, the FAA must develop a detailed set of procedures that describe when pilots and controllers should send D-Taxi messages (e.g., prior to push back, after push back, stopped on a ramp spot). Alternatively, Human Factors experts could work with the appropriate FAA office to develop and test procedures to determine which one is the most efficient and best supports the controllers' tasks. The FAA and researchers must consider all potential uses of data link when developing and testing such procedures.

When introducing new interfaces in a HITL simulation, the participants should receive as much training as possible to maximize their familiarity with the interface. Familiarity with the interface may influence the participant's need to attend to that interface and result in an overall decrease in performance. Familiarity may also affect the amount of attention and time that the participant must devote to a display. An operator will acquire information quicker and use an interface more effectively as they gain experience with that interface.

Researchers must look more closely at the interaction between pilots and controllers in an integrated air-ground research platform. Examining air-ground integration issues would extend the scope of future HITL simulations to include both pilots and ATCT controllers to examine human factors issues in a more realistic communications environment. In particular, an integrated air-ground simulation would provide better estimates of the duration of delays that may be associated with pilot responses to D-Taxi clearances.

Researchers should consider off-nominal conditions and how these conditions may affect the use, or lack of use, of data link. Off-nominal conditions should include situations that may have a large effect on surface movement operations, such as an unplanned closing of a taxiway or taxiway segment or a change in the active runway configuration.

Previous research, such as that by Stephenson (2007), suggests that D-Taxi may not be as useful when controllers must operate under high workload and with complex taxiway structures. However, this result was, in part, an artifact of the methodology used, and most airports in the United States are designed to minimize or completely remove complex taxi routes. Therefore, extending the current line of research to examine more complex taxiway structures is probably not worthwhile. Instead, researchers could improve future HITL simulations by introducing ramp activities, including aircraft pushing back from and arriving to terminal gates. Including ramp movements would also allow researchers to add new tools that are anticipated for future use in ATCTs. For example, surface TBOs suggest that controllers will have decision support tools, such as an arrival and departure queue management system (e.g., Briton & Atkins, 2009).

In summary, the controllers who participated in this experiment preferred the ability to issue D-Taxi clearances. They were able to use the TODDS GUI to quickly and easily construct and issue D-Taxi clearances. Another design iteration of TODDS is needed to address the identified usability issues and to further reduce the overall error rate. The use of D-Taxi reduced voice radio frequency congestion without increasing heads-down time or workload. Even though the delays associated with Data Comm caused aircraft to wait on the ramp longer, there was some indication that D-Taxi clearances for departure aircraft may improve the overall efficiency and safety of surface operations by reducing the duration of taxi-out operations and the potential for pilot readback and controller hearback errors. The FAA should continue to develop procedures for D-Taxi and to address any outstanding human factors issues on the way to implementing Data Comm for the Segment 2 timeframe. The HITL simulation capabilities should be augmented to include ramp movements and tools or decision support systems that controllers may use in the future to ensure that the advantages provided by D-Taxi are not mitigated by the interaction with other related systems.

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Acronyms

33L	Runway 33 Left
33R	Runway 33 Right
AA	Arrival-Arrival
AD	Arrival-Departure
ANOVA	Analysis of Variance
AOI	Area of Interest
ARTCC	Air Route Traffic Control Center
ASDE-X	Airport Surface Detection Equipment – Model X
A-SMGCS	Advanced Surface Movement Guidance and Control System
ATCT	Airport Traffic Control Tower
ATIS	Automatic Terminal Information Service
BOS	Boston Logan International Airport
CPC	Certified Professional Controller
Data Comm	Data Communications
DD	Departure-Departure
DESIREE	Distributed Environment for Simulation, Rapid Engineering, and Experimentation
D-OTIS	Data Link Operational Terminal Information System
D-Taxi	Digital Taxi
η^2	Eta-Squared Test Statistic
EDCT	Expected Departure Clearance Time
EMMA2	European Airport Movement Management by A-SMGCS
ER	Error Rate
F	*F*-Test Statistic
FAA	Federal Aviation Administration
FDE	Flight Data Element
FEWS	Future En Route Workstation
FTWS	Future Terminal Workstation
G	Grubbs Test Statistic
GMU	George Mason University
GUI	Graphic User Interface
HITL	Human-In-The-Loop

HMI	Human-Machine Interface
HSD	Tukey's Honestly Significant Difference
LAK	Logical Acknowledgment
LO	Land Over
NAS	National Airspace System
NextGen	Next Generation Air Transportation System
OTW	Out-The-Window
PEQ	Post-Experiment Questionnaire
PSQ	Post-Scenario Questionnaire
PTT	Push-To-Talk
RDHFL	Research, Development, and Human Factors Laboratory
RI	Runway Incursion
SME	Subject Matter Expert
STARS	Standard Terminal Automation Replacement System
TBO	Trajectory-Based Operation
TGF	Target Generation Facility
TODDS	Tower Operations Digital Data System
TRACON	Terminal Radar Approach Control
WAK	Workload Assessment Keypad
WT	Wake Turbulence

Appendix A

Informed Consent Statement

Informed Consent Statement

I, ______________________________, understand that this study, entitled "Data Communications – Segment 2 for Airport Traffic Control Towers" 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 high-fidelity 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:

Each participant will possess skills at an Airport Traffic Control Tower (ATCT) facility rated as Level 10 or higher. Because our simulated ATCT environment is similar to a configuration of Boston Logan International Airport (BOS), controllers from BOS may not participate to ensure valid results. All participants must have normal, or corrected to normal, vision. All participants must be able to stand for up to 1.5 hours without a break.

The participants will arrive at the Research, Development, and Human Factors Laboratory (Building 28) in groups of two and will participate over 3 days. Each participant will complete ATCT tasks at both the ground and local positions. The first day of the study will consist of a project briefing, equipment familiarization, touchscreen training, and practice scenarios. During the second day, the participants will work practice and experimental scenarios. During the third day, the participants will complete the experimental scenarios and complete a final debriefing. 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 control airport traffic under three different experimental conditions: voice only, 40% Data Comm, and 75% Data Comm. The participants will provide online ratings of subjective workload during each scenario. After each scenario, the participants will complete questionnaires to evaluate the impact of the alternative procedures on participant workload and acceptance. In addition, experimenters will observe and take notes during each scenario to further assess the Data Communications – Segment 2 concepts. The simulation will be audio-video recorded so researchers can derive objective measures and 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 methods and procedures for use in ATCTs. My data will help the FAA to establish the feasibility of these methods and procedures within such an environment.

Participant Responsibilities:

I am aware that to participate in this study I must be a current Certified Professional Controller in the Terminal specialty. I will control traffic and answer any questions asked during the study to the best of my ability. I will not discuss the content of the experiment with other potential participants until the study is completed.

Participant Assurances:

I understand that my participation in this study is completely voluntary and I can withdraw at any time without penalty. I also understand that the researchers in this study may terminate my participation if they believe it is 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. Truitt. 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 statement. I understand its contents, and I freely consent to participate in this study under the conditions described. I understand that, if I want to, I may have a copy of this form.

Research Participant:____Date:__________

Investigator:____Date:__________

Witness:____Date:__________

Appendix B

Biographical Questionnaire

Participant # ________ Date _________

Biographical Questionnaire

Instructions:
This questionnaire is designed to obtain information about your background and experience as a Certified Professional Controller. 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 C

Touchscreen Training Instructions

Participant Instructions for Touchscreen Training

The touchscreen training will last about 2 hours. Please read the following instructions at your own pace. Once you have finished reading the instructions, you may ask the experimenter any questions that you have about the training.

Standing position, centered on the touchscreen

Please remain standing during the training with your body centered over the line on the floor. This will ensure that your body is centered on the touchscreen. Keeping your body centered on the touchscreen will prevent you from committing errors due to parallax (i.e., off-angle viewing). The experimenter will adjust the touchscreen to ensure that you are looking directly at the screen so that we can ensure optimal performance.

Task Description

You will be touching and dragging buttons on the touchscreen during 30 different scenarios. Each scenario consists of a number of trials in which you will perform a particular task for a particular button size. During the scenarios, you will see 10 different button sizes, and you will have three different tasks to perform with each button size. The tasks are to select a single button, select two buttons in sequence, and drag a button to a target area. You will start with the largest button size and perform all three tasks for that button size. The buttons (and target zone in the third task) will appear at random locations on the touchscreen. After completing all three tasks for a button size, you will perform all three tasks again with the next button size. The buttons will continue to change in size until you have performed all three tasks for each of the 10 button sizes.

Using the index finger of your dominant hand, you will perform a minimum of 50 trials and a maximum of 100 trials during each scenario. You must try to achieve 10 successful trials in a row. The streak must occur at or after the minimum number of trials. For example, if you perform trials 41 through 50 without an error – that is, 10 consecutive "hits" – the scenario will end because you will have completed a streak of 10 and completed the minimum number of trials. If you have not achieved a streak of 10 consecutive hits after reaching the minimum number of trials, the scenario will continue until you achieve the streak or until you reach the maximum number of 100 trials.

The button border will highlight in green when you complete a successful trial (i.e., a hit). The button border will highlight in red when you fail a trial (i.e., a "miss"). You can view a running tally of your streak, hits, and misses in the bottom right corner of the touchscreen. After completing a scenario, you will have the option of taking a 5-minute break before starting the next scenario.

When selecting buttons, a miss will be recorded if your touch lands outside of the button's border or if you touch and drag a button simultaneously. Therefore, touches require accuracy and concentration. The dragging task requires that you to touch and drag a button into a target area. When dragging a button across the screen, your fingertip must remain in contact with the touchscreen. Lifting your finger from the touchscreen before placing the button completely inside the target area will result in a miss. Before starting the scenarios, the experimenter will demonstrate hits and misses for each of the three tasks (selecting a single button, selecting two buttons consecutively, and dragging a button to a target area), and you will have 10 practice trials with each task.

Accuracy versus Speed
When selecting a button, use the index finger of your dominant hand and aim for the center of the button. Please perform all of the tasks and trials as accurately as possible. Do not sacrifice accuracy to increase speed.

If you have any questions, please ask the experimenter now. If you have questions during the training, please feel free to ask.

Appendix D

Integrated TODDS Training Protocol

Integrated TODDS Training Protocol

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. Weather information box
    d. Placement of the EFD lists (Ctrl-p)
    e. Noun-Verb interaction style
        i. Select object to act upon
        ii. Select action to perform
        iii. Automatic object deselect
    f. 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
    g. Touch versus Slew
        i. Touch is for EFD interaction
        ii. Slew if for ASDE-X interaction
    h. Owned versus 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. Readout Area
    e. Change Runway/Intersection Assignment
    f. Resequence FDE
    g. Move Data Block
    h. Highlight Flight Data
    i. Change Assigned Heading
    j. Change Assigned Altitude
    k. Change Assigned Heading and Altitude
    l. Acknowledge Heading/Altitude Change
    m. ATIS update
    n. Weather Information Box
    o. Generic Timer
        i. Set
        ii. Monitor
        iii. Acknowledge Expired Timer
    p. Aircraft Specific Timer
        i. Set
        ii. Monitor
        iii. Acknowledge

q. Transfer FDE
r. Recall FDE
s. Digital Taxi Clearance
    i. Indicators
    ii. Canned routes
    iii. User-defined routes
        1. Creating
        2. Saving
        3. Editing
    iv. Conformance monitoring
    v. Cancel clearance

Appendix E

Workload Assessment Keypad Instructions

WAK Instructions

(The full set of instructions will be read at the beginning of each test day). An abbreviated set of instructions will be read prior to each experimental run. The abbreviated instructions will omit the first paragraph below.)

One purpose of this research is to obtain an accurate evaluation of controller workload. By workload, we mean all the physical and mental effort that you must exert to do your job. This includes maintaining the "picture," planning, coordinating, decision making, communicating, and whatever else is required to maintain a safe and expeditious traffic flow. Workload is your perception of how hard you must work to perform all of the tasks necessary to meet these demands, not necessarily a measure of how much traffic you are working. Workload levels fluctuate. All controllers, no matter how proficient, will experience all levels of workload at one time or another. It does not detract from a controller's professionalism when he indicates that he is working very hard at certain times or that he is hardly working at other times.

Every 5 minutes the WAK device, located at your position, will emit a brief tone and the 10 buttons will illuminate. The buttons will remain lit for 20 seconds. Please tell us what your workload is at that moment by pushing one of the buttons numbered from 1 to 10.

At the low end of the scale (1 or 2), your workload is low – you can accomplish everything easily. As the numbers increase, your workload is getting higher. The numbers 3, 4, and 5 represent increasing levels of moderate workload where the chance of error is still low but steadily increasing. The numbers 6, 7, and 8 reflect relatively high workload where there is some chance of making errors. At the high end of the scale are the numbers 9 and 10, which represent a very high workload, where it is likely that you will have to leave some tasks unfinished. Feel free to use the entire rating scale and tell us honestly how hard you are working at the instant that you are prompted. Do not sacrifice the safe and expeditious flow of traffic in order to respond to the WAK device.

Appendix F

Post-Scenario Questionnaire

Participant #_____ Date ________ Touch w/ _____ Position_____ Run # _____ Scenario _____

Post-Scenario Questionnaire

Please answer the following questions based upon your experience in the scenario just completed. Respond to Items 1-6 if you just completed a Data Comm scenario. Otherwise, begin with Item 7.

1. Rate the effort needed to **recognize aircraft that were Data Comm equipped**.	Extremely Low	① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩	Extremely High

Comments:

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2. Rate the effort needed to **recognize a request for a D-Taxi clearance**.	Extremely Low	① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩	Extremely High

Comments:

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3. Rate your ability to **recognize an acknowledged D-Taxi clearance**.	Extremely Low	① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩	Extremely High

Comments:

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4. Rate your ability to **recognize a failed D-Taxi clearance**.	Extremely Low	① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩	Extremely High

Comments:

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Participant #_____ Date ________ Touch w/ _____ Position_____ Run # _____ Scenario _____

5. Rate the effort needed to **issue a canned D-Taxi clearance**.	Extremely Low	① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩	Extremely High

Comments:

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6. Rate the effort needed to **issue a user-defined D-Taxi clearance**.	Extremely Low	① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩	Extremely High

Comments:

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7. Rate the effort needed to **issue a taxi clearance via voice.**	Extremely Low	① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩	Extremely High

Comments:

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8. Rate the effort needed to **maintain flight data**.	Extremely Low	① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩	Extremely High

Comments:

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Participant #_____ Date ________ Touch w/ _____ Position_____ Run # _____ Scenario _____

9. Rate the effort needed to **find necessary flight information**.	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High

Comments:

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10. Rate the effort needed to **find necessary weather information**.	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High

Comments:

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11. Rate the effort needed to **transfer flight data**.	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High

Comments:

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12. Rate your ability to **detect aircraft on the runway**.	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High

Comments:

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Participant #_____ Date ________ Touch w/ _____ Position_____ Run # _____ Scenario _____

13. Rate your **awareness for current aircraft locations**.	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High

Comments:

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14. Rate your **awareness for projected aircraft locations**.	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High

Comments:

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15. Rate your **awareness for potential runway incursions**.	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High

Comments:

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16. Rate your **awareness of the overall traffic situation**.	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High

Comments:

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Participant #_____ Date ________ Touch w/ _____ Position_____ Run # _____ Scenario _____

17. Rate your **workload due to controller-pilot communication**.	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High

Comments:

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18. Rate your **overall workload**.	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High

Comments:

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19. Rate the **safety of operations**.	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High

Comments:

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20. Rate the **necessity of coordination** between the ground and local positions.	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High

Comments:

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Participant #_____ Date ________ Touch w/ _____ Position_____ Run # _____ Scenario _____

21. Do you have any additional comments or clarifications about your experience during this scenario?

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Appendix G

Post-Experiment Questionnaire

Post-Experiment Questionnaire

Please answer the following questions based upon your overall experience in the experiment you just completed.

1. Rate the **readability of the readout area** on the TODDS.	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High

Comments:

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2. Rate the **readability of the weather information box** on the TODDS.	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High

Comments:

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3. Rate the **readability of the flight data elements** on the TODDS.	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High

Comments:

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4. Rate the **readability of the data blocks** on the TODDS.	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High

Comments:

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5. Rate the **overall effort needed to use the touchscreen** when using the TODDS.	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High

Comments:

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6. What effect do you think **D-Taxi** will have on your ability to control traffic in the tower?	Negative Effect	①②③④⑤⑥⑦⑧⑨ | None	Positive Effect

Comments:

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7. Rate the effort needed to **manage a complete Data Comm failure**.	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High

Comments:

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8. Rate the effort needed to **detect an aircraft that deviated from a taxi clearance that was issued via voice**.	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High

Comments:

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9. Rate the effort needed to **<u>detect</u> an aircraft that deviated from a taxi clearance that was issued via D-Taxi**.	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High

Comments:

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10. Rate the effort needed to **<u>manage</u> an aircraft that deviated from a taxi clearance that was issued via voice**.	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High

Comments:

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11. Rate the effort needed to **<u>manage</u> an aircraft that deviated from a taxi clearance that was issued via D-Taxi**.	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High

Comments:

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12. Rate how useful D-Taxi would be for taxi-in operations.	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High

Comments:

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13. Under what circumstances would you not use D-Taxi?

14. What is the greatest benefit(s) of D-Taxi?

15. What is the biggest problem(s) with D-Taxi?

16. In order of preference, what additional features would you desire for D-Taxi?

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

Comments:

18. What is the greatest benefit(s) of the TODDS?

19. What is the biggest problem(s) with the TODDS?

20. In order of preference, what additional features would you desire for the TODDS?

21. Do you have any additional comments regarding the experiment?

Appendix H

Justification for Repeated Measures ANOVA Procedure

Justification for Repeated Measures ANOVA Procedure

Experimenters often use a repeated measures design to control, and thereby reduce, the error variability in the data due to differences between participants. Too much error variability may prevent the researcher from detecting significant effects of experimental conditions (treatments). However, we must consider some special statistical assumptions when analyzing data from a repeated measures design. In a repeated measures design, the experimenter has set up the conditions such that participants in certain parts of the experiment are more alike than participants in other parts of the experiment. For example, participants who have expertise in one technical specialty are more similar to one another than to participants in a different technical specialty. Therefore, given repeated measurements, there is a correlation between the scores of participants in the same group (i.e., similar technical specialty and area-specific knowledge). The correlation of scores among participants also results in dependencies among experimental conditions.

Researchers initially justified the use of the *F* test in a repeated measures design by assuming that the condition of compound symmetry exists across conditions or participants. However, for the condition of compound symmetry to be met, each treatment must have the same true variance over all conditions (pooled within-group), and the covariance (across participants) for each pair of treatments must be a constant. Although the assumption of compound symmetry is sufficient to justify the use of the *F* test[2] in a repeated measures design, it is not a necessary condition. In fact, the compound symmetry assumption is very strict and not likely to hold true, especially in experiments using a repeated measures design. The compound symmetry assumption does not have to be met to justify use of the *F* test. Huynh and Feldt (1970) and Rouanet and Lepine (1970), among others, have shown that the circularity assumption (or sphericity assumption), which is both mathematically necessary and sufficient, can be made to support the use of the *F* test in repeated measures designs. The circularity assumption simply states that the components of the within-subjects model are orthogonal (independent) components. For more information on the assumptions associated with repeated measures designs, refer to Hays (1988) and Kirk (1982).

One way to ensure that the statistical assumptions associated with a repeated measures design are satisfied is to analyze the data using the multivariate analysis of variance (MANOVA) method. In the MANOVA method, the different scores from each participant are handled as if they are actually scores from different variables. This method alleviates the necessity of the assumptions associated with the analysis of variance (ANOVA) *F* test. Significant MANOVA effects are then tested further by ANOVA *F* tests and particular post hoc comparisons. However, the MANOVA approach may not be feasible for small sample designs where degrees of freedom are insufficient.

Another way to analyze data from a repeated measures design while accounting for the circularity assumption is to implement a three-step testing method, as suggested by Hays (1988) and Kirk (1982). In this method, the data is first analyzed by an ANOVA. If the result is not significant, then the analysis stops – and the researcher must conclude that there is no effect of

[2] The *F* test is justified (i.e., valid) when the reported *F* values adhere to the *F* distribution.

the independent variables in question. If the ANOVA is significant, then the Geisser-Greenhouse (G-G) *F* test (or conservative *F* test) is conducted (Geisser & Greenhouse, 1958). Essentially, the G-G *F* test adjusts the degrees of freedom used to calculate the *F* statistic to make the test more conservative (i.e., less likely to find a significant difference by chance, where none exists). The G-G *F* test ensures that the researcher is not capitalizing on chance or on violations of the circularity assumption. If the G-G *F* test is significant, then the result is highly significant. If the G-G *F* test is not significant, then the circularity assumption may have been violated and the Box adjustment (Huynh-Feldt [H-F] *F* test or adjusted *F* test) is calculated (Huynh & Feldt, 1970). If the H-F *F* test is computed, then that result is the final determinant regarding whether a significant effect is present or not. We used this later method for the present experiment. We conducted multiple comparisons of means using Tukey's Honestly Significant Difference (HSD) post hoc test. If a significant main effect or interaction of main effects was found, then the Tukey's HSD post hoc test was computed to explain the interaction for all relevant analyses.

We selected this three-step approach to minimize the probability of a Type II error (i.e., False acceptance of the null hypothesis, or finding no effect where one actually exists) while sacrificing an increase in the probability of a Type I error (i.e., False rejection of the null hypothesis, or finding an effect where none actually exists). We also conducted a number of planned comparisons to examine conditions of interest more closely. Such an approach will increase the likelihood that the statistical analyses will detect effects caused by the experimental conditions. To balance this arguably liberal approach to data analysis, we used the Tukey HSD to conduct post hoc tests, rather than calculating simple main effects.

Appendix I

Participants’ Comments from the Post-Scenario Questionnaire

PSQ Item 1 - Rate the effort needed to recognize aircraft that were Data Comm equipped.

Ground – 40% Data Comm

- Best part of data comm.
- Δ - Does stick out.
- You're looking for it because you are motivated to use the equipment and not have to say much on frequency.
- Easy.
- Clear symbols.

Ground – 75% Data Comm

- Easy to tell who has what.
- Symbols were clear and easy to understand quickly.

PSQ Item 2 – Rate the effort needed to recognize a request for a D-Taxi clearance.

Ground – 40% Data Comm

- Easy.

Ground – 75% Data Comm

- The aircraft would just pop up in your pending list. Would be nice if they would show in pending but would flash or flash as they pop in your bay.
- Easy.
- Symbols were clear and easy to understand quickly.

PSQ Item 3 – Rate your ability to recognize an acknowledged D-Taxi clearance.

Ground – 40% Data Comm

- o - Does stick out.
- Easy.

Ground – 75% Data Comm

- The doughnut is small but noticeable.
- Very usable.
- Symbols were clear and easy to understand quickly.

PSQ Item 4 – Rate your ability to recognize a failed D-Taxi clearance.

Ground – 40% Data Comm

- Like the red but needs to stand out a little more.
- Easy.

Ground – 75% Data Comm

- Turns red, perfect!
- Very usable.
- Symbols were clear and easy to understand quickly.

Local – 75% Data Comm

- I think it might be red?

PSQ Item 5 – Rate the effort needed to issue a canned D-Taxi clearance.

Ground – 40% Data Comm

- Just need to read first fix and runway assignment.
- Easy.

Ground – 75% Data Comm

- Got used to just acknowledging and send rather than pay attention to route.
- No problem noted.
- Easy.
- System seems well suited for the normal "canned" routes.

PSQ Item 6 – Rate the effort needed to issue a user-defined D-Taxi clearance.

Ground – 40% Data Comm

- Easy.
- Seems like it would be a little tougher than the "canned" routes.

Ground – 75% Data Comm

- Nice but I'm afraid that controllers might become complacent. Suppose a route had an error and omitted a hold short or a runway became active then?
- Not used.
- Haven't done one yet.
- Very easy. Review, verify hold short points, send. Nice.

PSQ Item 7 – Rate the effort needed to issue a taxi clearance via voice.

Ground – 0% Data Comm

- With high volume.
- Basic clearance once airspace was learned.
- Very easy, might be my years of experience?

Local – 0% Data Comm

- For obvious reasons - Just wasting "airtime" of the position.

Ground – 40% Data Comm

- Easy.

Ground – 75% Data Comm

- We do that now.
- Typical to today's environment.

PSQ Item 8 – Rate the effort needed to maintain flight data.

Ground – 0% Data Comm

- High to start. Time with the data will help lower the effort.
- Moderate - still missing buttons on first attempt.
- The new system is that "new." It requires just a little bit of learning.

Local – 0% Data Comm

- Overlapping the runways.
- Only issue is data tag overlap.
- The information was all there. Sometimes I just didn't know how to get it, or move it.
- It's a busy screen.
- Just a "new" tool to learn. I can see becoming very accustomed to using the "paperless" strip.

Ground – 40% Data Comm

- Lots of info in front of position.
- Easy.
- I let a runway mis-assignment go over D-Taxi. Should've been 33L but went of 27. I don't know that Local control noticed. I should've caught it!

Ground – 75% Data Comm

- This system takes some getting used to. The flight data block clogs or clutters the screen. Colors are nice but distracting in general. It needs a few changes,

otherwise there is an extreme amount of data to process and more heads down time.
- Couldn't remember how to change runway.
- Easy.
- The toughest part is trying to give Local control a good feed of aircraft (no back to backs).

Local – 75% Data Comm

- Too much info impossible to tell the difference on aircraft at different runways.
- Hard to keep the list up to date. Trying to keep the dead wood out of the bay.
- Not necessary, as data blocks show necessary information.
- Sometimes the data block would shift as I looked at it which made it more difficult.

PSQ Item 9 – Rate the effort needed to find necessary flight information.

Ground – 0% Data Comm

- Easy. Nice display, but haven't used it much.
- Seems pretty straightforward.

Local – 0% Data Comm

- At critical times data blocks were hard to locate.
- A little less effort today needed. Still the screen was very cluttered.
- Tags would overlap.
- The flight information is easy to find once you know where to find it. Sometimes it is hard to find because information is on top of information.
- Low, because selecting the aircraft shows the flight information.
- Very easy to do this.

Ground – 40% Data Comm

- Easy to display.
- Data blocks kept covering each other.

Local – 40% Data Comm

- Data tags overlapping need to sort out to find which runway were taxing to.

Ground – 75% Data Comm

- Layout need some improvement. Don’t really care about taxi times.
- Easy.
- Very clear.

Local – 75% Data Comm

- As with #8, 9, 11 overlapping data blocks and data in "crossing" leaderlines can lead to a serious error.
- Too much clutter. Way too much heads down time. Felt like I was a manager of a computer not a controller.
- Not necessary, as data blocks show necessary information.

PSQ Item 10 – Rate the effort needed to find necessary weather information.

Ground – 0% Data Comm

- Noticed the □'s pop up on flight plan more than flashing ATIS code.
- Haven't noticed weather information.
- Easy!

Local – 0% Data Comm

- To look up and see it is very easy.
- Did not look for it.
- Very easy to do this.

Ground – 75% Data Comm

- Easy.
- Haven't looked other than ATIS/wind/altimeter.
- Well placed. Very easy.

Local – 75% Data Comm

- No problems noted.
- Did not look for it, other than ATIS.

PSQ Item 11 – Rate the effort needed to transfer flight data.

Ground – 0% Data Comm

- If you have to search it can be distracting to your job.

- Easy.
- This seems easy from Ground to Local. I noticed sometimes when Local is busy, things might be forced onto (into) my electronic flight data list, I'm sure it's not on purpose.

Local – 0% Data Comm

- To departure only was difficult.
- Sometimes difficult to select correct box for departures.
- Not too bad. It's difficult to find the strip you're using. When an aircraft lands on the runway he turns yellow. I look for the yellow then switch 'em to ground.
- To departure is improving.
- Would select departure rather than ground control.
- The information isn't difficult to transfer.
- Moderate because of the volume of aircraft.
- Right now this is the function requiring most of my attention when working Local control. On Ground it's the other end of the scale.

Ground – 40% Data Comm

- Just get use to touch screens.

Local – 40% Data Comm

- Multi-task. Just something we get used to.
- Maybe a floating button for contact departure?
- Kept transferring aircraft that were supposed to be on ground control to departure.
- There's a lot of information on the screen.
- I think I'm getting into a groove on Local. Switching to Departure.

Ground – 75% Data Comm

- A pain if you forget but ok.
- Easier.
- Very easy.

Local – 75% Data Comm

- Too much work to switch to ground or departure. Data should automatically switch.

- It is easy to do but still not getting it to departure enough.
- Still not using lists very often.
- I seem to be having a hang-up when switching aircraft to Departure. I think I just thought of a way to help. I'll try it next session.

PSQ Item 12 – Rate your ability to detect aircraft on the runway.

Ground – 0% Data Comm

- Data blocks overlap runways too easily.
- Love the yellow data tag.
- Other than data block overlay, not bad.
- Easy.

Local – 0% Data Comm

- Arrival aircraft data tag lost among aircraft on taxiway E.
- Still enjoy the yellow it's very eye catching.
- Data blocks get covered up.
- Good, since I'm working them.
- Easy…becomes a little confusing as aircraft cross the runway to another runway (same color).

Local – 40% Data Comm

- Sometimes data blocks would cover up.
- They would get lost in the cluster of data blocks that cover the runway.

Ground – 75% Data Comm

- Like the change of color but too many color changes. Would recommend red X on the approach runway when traffic crosses.
- Easy to see.

Local – 75% Data Comm

- When you look at the window great. When you look at the display, ok. Like the yellow.
- Very easy to see aircraft on a runway.
- Easy to see, but sometimes difficult to remember information was cleared to cross. Using blue tags to help.

PSQ Item 13 – Rate your awareness for current aircraft locations.

Ground – 0% Data Comm

- Arrivals tend to be difficult for me to identify with defaulting to center of screen.
- Just got to get used to the airspace.
- No problems seeing where planes are.

Local – 0% Data Comm

- The way the bays are displayed are difficult to tell the difference for different runways.
- Got tired from volume.
- Compact airspace.

Ground – 40% Data Comm

- Once you move tags no problem.
- Sometimes forget about aircraft on crossing runway.

Local – 40% Data Comm

- Good information and hold short data block.
- Can lose picture quickly with volume presented and tasks needed to complete.

Ground – 75% Data Comm

- Not difficult.

Local – 75% Data Comm

- Good. Looking out window gives you a great picture but the display is cluttered. It's difficult to find aircraft within all the data tags.
- Using both displays is helping.

PSQ Item 14 – Rate your awareness for projected aircraft locations.

Ground – 0% Data Comm

- Expected them to do what was told.
- No problems seeing future conflicts.

Local – 0% Data Comm

- I feel like I'm still in the learning curve.

Ground – 40% Data Comm

- Just position (out window) awareness.

Local – 40% Data Comm

- Must move data blocks.

Ground – 75% Data Comm

- High.

Local – 75% Data Comm

- Not difficult.

PSQ Item 15 – Rate your awareness for potential runway incursions.

Ground – 0% Data Comm

- Missed one. Didn't look out window. May have been taxiing to catch up.
- I can see where the potential problems are at a very "focused" point of conflicts.

Local – 0% Data Comm

- Hold short indicator on outbound aircraft data tags helps.
- Not too bad this time around.
- I need an indicator to know when I have cleared an aircraft to cross.
- Tough to say right now because I'm still learning the projected aircraft locations.

Local – 40% Data Comm

- Sometimes forget about aircraft on crossing runway.
- Aware but reacted slowly on occasion.

Ground – 75% Data Comm

- Too much info if you focus on display.
- High.

- This session I would even use the "hold short" button to force it onto voice taxied aircraft.

Local – 75% Data Comm

- When you cross the runway red X should be on the approach end. Also I didn't see the green hold bars the ASDE-X offers.
- Still getting use to system and layout, but trying to get head up more.

PSQ Item 16 – Rate your awareness of the overall traffic situation.

Ground – 0% Data Comm

- Lots of aircraft, but route not that complex. Tried to separate data tags.

Local – 0% Data Comm

- At times it was very complex but overall ok.
- Very busy traffic. Still a big learning curve.
- Sometimes my judgment isn't as good as normal but overall I feel strong.

Ground – 40% Data Comm

- Between ground information and out of window no problem.

Local – 40% Data Comm

- Must set priority and comfort level for position. Once you are there, not too bad.
- Starts out high but goes down after time on position and traffic volume.
- Poor. Never considered aircraft types or speed of arrivals.

Ground – 75% Data Comm

- Increases over time.
- Ground not too difficult.

Local – 75% Data Comm

- It was brutal. I didn't get the picture from the strip bay. Almost always I'd use the data tag which became cluttered.
- Very aware that this is busy.

PSQ Item 17 – Rate your workload due to controller-pilot communication.

Ground – 0% Data Comm

- Not bad. Not many readbacks.

Local – 0% Data Comm

- Light.
- They do very well.
- Most calls have been timely, it is what it is.

Ground – 40% Data Comm

- Lots to say.
- Voice versus data comm.

Local – 40% Data Comm

- Moderate.

Ground – 75% Data Comm

- Good read back by pilots.
- I don't see it as a reduction of workload but maybe a realignment of workload.

Local – 75% Data Comm

- They do well.

PSQ Item 18 – Rate your overall workload.

Ground – 0% Data Comm

- Somewhat busy, but some lulls to catch up.

Local – 0% Data Comm

- Varied from 4-7.
- Busy, busy - real world would require help pressing buttons.

Ground – 40% Data Comm

- Getting use to position, once you are becomes easier.

Local – 40% Data Comm

- Lots to do again, multitask.
- Busy. Many tasks to complete to be consistently good.

Ground – 75% Data Comm

- Ground control was good.
- Moderate.

Local – 75% Data Comm

- I was a manager of a CPU, not a controller. Adjust colors, reduce clutter, separate runway bays better.
- Still high.

PSQ Item 19 – Rate the safety of operations.

Ground – 0% Data Comm

- Sometimes things just work out.
- Ground was very safe. For the record, I would've said something to local when he had the runways full of arrivals at the same time as departures, in the real world.

Local – 0% Data Comm

- Mainly due to unfamiliarity with the layout.
- Too many aircraft crossing active runways.
- I don't know if most operations were legal but it looked ok.
- Did not provide wake turbulence. Rarely consider aircraft type.
- Any time a crossing is involved the safety is at risk. Just my opinion.

Ground – 40% Data Comm

- Hopefully, like PDC [Pre Departure Clearance].
- Ground was safe.

Local – 40% Data Comm

- Still getting used to it - (TODDS). Once proficient will enhance safety tremendously.

- Lots of good information to use.
- Had too many go arounds and ran them too tight.

Ground – 75% Data Comm

- Not difficult.

Local – 75% Data Comm

- On local very low. Too much heads down display time.
- Getting better at timing, etc.

PSQ Item 20 – Rate the necessity of coordination between the ground and local positions.

Ground – 0% Data Comm

- Minimum because of the few 33R arrivals.

Local – 0% Data Comm

- No problems noted.
- Minimal due to 33R arrivals being low.

Ground – 40% Data Comm

- For runway crossings at 33L/N.

Local – 40% Data Comm

- We had great coordination!
- Minimal.

Ground – 75% Data Comm

- At certain facilities local is required to cross aircraft.
- Only on crossing runway at 33L/N.
- To cross 33L at N - would be nice if local control kept them and crossed them.
- Minimal.

Local – 75% Data Comm

- Minimal.

PSQ Item 21 – Do you have any additional comments or clarifications about your experience during this scenario?

Ground – 0% Data Comm

- A little too long. Light traffic without complexity.
- Useful data info. Just too much at times. Requires constant repositioning of data info in order to read and provide a sequence. Inbound aircraft (arrivals) need to be another color.
- I've noticed that the flight strips immediately appear in the pending sections. Our flight strips are normally posted 30 minutes in advance when you send a clearance PDC. If there was a way to set up the pending list so people can customize it. Lastly its hard to tell the difference between an arrival and a departure on the display.
- Still getting use to equipment and airspace.

Local – 0% Data Comm

- Local control data blocks and flight data bays are confusing.
- The arrival aircraft default to inward position (got lost with other data blocks).
- Any adjustment of data for the proper runway assignments (Distracting).
- On local position, I found it distracting to try to find a departed aircraft's data when switching to departure. The info seems hard to pick out of the tab list.
- My overall scanning improved today. Tried to use the strip bay more rather than data tags. Don't like the arrival bay. Perhaps if an airplane sits on a runway for more than 2 minutes an alert would flash. I forgot I put someone in position with a guy on final. Without offsetting the strip it was too easy to forget he was there out on the runway.
- Liked using blue data blocks to indicate crossing/position and hold clearances.

Ground – 40% Data Comm

- This does have great potential!!
- In the pending flight plan it's helpful to have the first fix on the strip. When you issue a D-Taxi without looking at the route you assume it will go to the corrrect runway.
- Would pilots with a timed out D-Taxi call or monitor for taxi instructions?
- Starting to get easier with typical traffic situations.

Local – 40% Data Comm

- Just time on position to get use to information and tasks performed.
- Much better this time around.

- Started off poorly, but eventually found my groove. However, I did not feel I handled the traffic well. Would rate about a five overall.

Ground – 75% Data Comm

- I would like to see an annotation for heavy aircraft. Without the annotation I tended not to issue it.
- Seems to be working!
- I like using the interface on ground control but we can't customize display settings. Clean up limited data tags in LDB data block.
- No. I think the ground part of this equipment is very good.
- Getting easier to manage traffic load.

Local – 75% Data Comm

- System areas need more organization. Data transfers can add workload and be last to be kept up with in busy situations.
- Data blocks up at runway 27 kept getting overlap. Also missed picking data blocks cleanly - aircraft landing kept jumping with the auto offset.
- Separate runway bays better. On local the flight strip needs to be offset when in position. Set up filters to limit amount of data blocks shown. Didn't need a runway timer for more than 3 minutes. The strip needs to stand out better when aircraft is in position.
- Felt better, but may not be prepared should we have an equipment malfunction, etc. Would like mileage markers on the ASDE display for arrivals.

Appendix J

Participants' Comments from the Post-Experiment Questionnaire

Participants' Comments from the Post-Experiment Questionnaire

PEQ Item 1 - Rate the readability of the readout area on the TODDS.

- Very readable, I just didn't use it.
- Great.
- Overall in laboratory it was good but I think in the field some colors/fonts/font sizes may need to be adjusted (or adjustable).

PEQ Item 2 – Rate the readability of the weather information box on the TODDS.

- I would've noticed with a slightly brighter setting.
- Put altimeter and other information in weather area.
- Sometimes easy to miss.
- Great.
- It catches your attention.

PEQ Item 3 – Rate the readability of the flight data elements on the TODDS.

- Too busy, not easily readable. First glance is just a jumble.
- The runways split was difficult to find (maybe different colors or larger break between runways).
- For ground OK but for local very difficult. Need to separate runway bays better.
- Great.
- If fonts and sizes were adjustable to customize per personal perferences it might rate higher.

PEQ Item 4 – Rate the readability of the data blocks on TODDS.

- Depends on data block size.
- That's why I never used the readout area.
- Way too cluttered not safe. Need to have limited data block filters.
- Overlap is bad. Plus it obscures seeing the runway.
- Bounce around a lot, but great.
- They seemed to know when/where to be to get into the way. Example - Arrival would have a data block in my way (because I spun the map) every time, requiring me to grab and drag (a look down function) every time.

PEQ Item 5 – Rate the overall effort needed to use the touchscreen when using the TODDS.

- Touch screen is very good.
- When data blocks got bunched up touching to separate was a little tough.
- Easy to use.
- Only because of unfamiliarity with the system.
- May have to make multiple taps but over all fine.
- It increased look down time, but it was useable.

PEQ Item 6 – What effect do you think D-Taxi will have on your ability to control traffic in the tower?

- Excellent, however reliance on the system causes you not to scan them (potential problem).
- I would love to see this in SLC tower.
- If used right with proper hold points.
- Much better, less talking even with Data Comm failure it was easier.
- On ground yes, tower (local) no effect.
- A lot of heads down time initially until I got used to it.
- After the learning curve, ground would be more boring.
- I love this idea! One problem - pilots won't just sit and wait, they will call if I don' t call them right away. Nothing can be done about that.

PEQ Item 7 – Rate the effort needed to manage a complete Data Comm failure.

- No problem easy to recover from failure.
- At this time but as controllers use the equipment it will be more difficult to go back to regular communications.
- User must be aware that a failure occurred.
- Business as usual.
- It isn't a deal breaker for sure.

PEQ Item 8 – Rate the effort needed to detect an aircraft that deviated from a taxi clearance that was issued via voice.

- Very noticeable - good feature.

- If you look out the window it's a 50/50 shot.
- Need to pay attention, have to learn the potential bad routes.
- When I ran it on ground control, way easy to see it. When it happened when I was local control, I found it distracting which I guess isn't good or bad it has both good and bad points. Good - it alerts me that someone is lost and protect myself/planes. Bad - I'm distracted from my primary function.

PEQ Item 9 – Rate the effort needed to detect an aircraft that deviated from a taxi clearance that was issued via D-Taxi.

- Great feature easy to see.
- Easier to see if a pilot deviated.
- More heads down time so initially it may take longer.
- Good indicator.
- Same as question 8. [When I ran it on ground control, way easy to see it. When it happened when I was local control, I found it distracting which I guess isn't good or bad it has both good and bad points. Good - it alerts me that someone is lost and protect myself/planes. Bad - I'm distracted from my primary function.]

PEQ Item 10 – Rate the effort needed to manage an aircraft that deviated from a taxi clearance that was issued via voice.

- Get to them quick enough and it wasn't a problem.
- Hard here because I'm not familiar with all the runways and taxiways.
- They could not hold short of taxiways.
- Easy, just reclear.
- Because I couldn't remember taxiway names made it tougher but wasn't very bad.

PEQ Item 11 – Rate the effort needed to manage an aircraft that deviated from a taxi clearance that was issued via D-Taxi.

- Hard here because I'm not familiar with all the runways and taxiways.
- They could not hold short of taxiways.
- Easy, just reclear.
- Same as above. [Because I couldn't remember taxiway names made it tougher but wasn't very bad.]

PEQ Item 12 – Rate how useful D-Taxi would be for taxi-in operations.

- Depends on current traffic. Not everyone exits at the same place and goes in to the same ramps.
- Just need to worry about conflicts and could come back with voice.
- Again done right could be a great tool.
- That might be more challenging.
- Could potentially cause issues with blocking runway exits and cause go-arounds.
- Very useful at complex airports.
- Controller wise I don't know of the benefit. I think it would increase pilot workload.

PEQ Item 13 – Under what circumstances would you not use D-Taxi?

- Weather, taxiway closures, emergencies, unfamiliar general aviation pilots.
- Rapidly changing weather conditions. IFR.
- I would always use it if available.
- I can't think of any.
- As a ground controller I would always want to use it. The only thing I can think of is if the system was completely down.
- I would use it as much as possible.
- I really couldn't think of a reason, except if system goes down, how current/capable would you be able to keep up with traffic.
- I don't know how useful it would be for ground delays or if any closures were present.
- None.
- EDCT [Expected Departure Clearance Time] "hold spots" and or weather days with constant changing flows.
- I can't think of any.
- Initially, under hard IFR conditions.
- If the pilot was unfamiliar, and needed progressive taxi instructions.
- I would always use it, if it was available.
- Emergencies primarily. I can't think of any more.

PEQ Item 14 – What is the greatest benefit(s) of D-Taxi?

- Reduces verbiage.
- No verbiage or read back errors. If you had a long involved route to issue.
- Less voice communications needed.
- Safety in issuing taxi instructions with "hold short" instructions.
- Greater situational awareness.
- Less voice communications and you already know what to expect from the pilots.
- Less talking on frequency.
- No confusion in taxi route, depending on airline no confusion with phraseology, i.e., foreign air carrier.
- Less communication on frequency!
- Reduced verbiage. Pilots can re-read their instructions.
- Participating aircraft flow smoothly on quiet days.
- Less frequency congestion. Shorter transmissions.
- D-Taxi reduces frequency chatter and standardizes portions of the ground operation.
- Speed of delivering taxi instructions also no hear back read back issues.
- No communications barrier.
- A reduction of "airtime" use.

PEQ Item 15 – What is the biggest problem(s) with D-Taxi?

- It can only be used in a "perfect world."
- Too much information to digest in small period of time to establish effective flow.
- I liked the D-Taxi. I found it hard to pick out departure aircraft from the list. I did get more comfortable with the list toward the end.
- Selecting buttons on screen.
- Some clutter on the screen and at busy times can be tedious.
- None I can think of.
- Ground not staying current/capable of working traffic via voice instructions.
- At our airport we sometimes take aircraft to the closest runway based on traffic flow. Unless our facility changes our SOP it would be very difficult to use.
- Tag clutter.
- Flexibility with editing taxi clearances issued already.

- When it goes into failure mode.
- Constantly having to move data tags around.
- Data block placement, overlap, congestion.
- Heads down and my fat fingers.

PEQ Item 16 – In order of preference, what additional features would you desire for D-Taxi?

- Not a big deal since I noticed most fairly quickly, but maybe have the data block flash after he receives it.
- Auto offset for specific runways. Color change inbound/landing aircraft.
- Canned SMGSS [Surface Movement Guidance Support System] routes.
- Hold short for taxiways.
- A brighter line divider on Local control display to differentiate the runways in the list.
- None I can think of.
- It might be nice to have a conflict alert box in which an aural alarm sounds. The aircraft in question appears in the box if it deviated from route.
- The list/bay is hard to navigate. No others I can think of.
- Automatic ATIS "checked" from the ACARS to the TODDS. Easier user interface to change a sent clearance or edit canned clearances.
- Some sort of memory jogger for when you're crossing runways.
- Make designations for departing runways.
- Preference sets to set up a way to get information where you want it on certain areas of the airport.
- Add H for heavy aircraft.
- Can't think of much more.

PEQ Item 17 – What effect do you think the TODDS will have on your ability to control traffic in the tower?

- Eventually, it will be advantageous.
- Pilots seem to do better with clearances received by D-Link.
- It enhances the overall picture with the D-BRITE and the ASDE-X.
- Will work great for ground.
- Need time to get used to, too much board management if not.

- We have to be careful. The TODDS creates heads down time. Requires lots of controller input.
- Again, this will be a great tool on VFR "stable conditions" days.
- Once used to it, traffic should expedite.
- I think it will be positive. I don't think it is perfect yet.
- After the learning curve, fun to use.
- In laboratory it's great but I don't know that it would affect my ability in a positive or negative way.

PEQ Item 18 – What is the greatest benefit(s) of the TODDS?

- Less coordination, more information, and the ability to work more aircraft.
- Data blocks on aircraft.
- Great for IFR/low ceiling conditions.
- Safety, reduced workload, accuracy.
- Greater situational awareness.
- Less voice communications (frequency congestion). I believe that it will help eliminate runway incursions.
- All information is right in front of you.
- Lots of information, cut frequency issues (volume).
- Everything you need is in front of you.
- All data is there and available.
- Combined ASDE-X/flight strip display.
- Less verbiage.
- When everyone is familiar and comfortable this system would help in IFR conditions.
- Speed and accuracy of taxi instructions. Also the touch screen to get things figured out without a trackball.
- No strips.
- It seems to be a nice combination of several pieces of equipment "ASDE-X Supercharged" which is nice to have a "central point" of focus is good.

PEQ Item 19 – What is the biggest problem(s) with the TODDS?

- Graphics, leader lines.

- Overlap problems on auto offset (landers toward middle of scope and I had touch time separating on departure from 27).
- Data positions are hard to manage - i.e., if you can't read the information you can't give the instruction. No instruction, no effective traffic flow.
- Data block overlap.
- Selecting buttons on screen.
- I cannot think of any major flaw that I did not like. As a local controller it may be more work (with the touch display) than some facilities are used to at that position.
- Getting acquainted with the equipment.
- Lots of info, at times too much hands on.
- The display is cluttered. Strips should be offset in bays (taxi into position and hold). Need runway activity button. Runway timers are distracting. Colors change too much. Departure strip not clearly noticeable.
- Tag overlap.
- User error and potential for computer errors.
- Putting them in the wrong drop list.
- Call signs getting on top of each other, selecting the incorrect data tag by accident.
- Lacks some human elements, such as offsetting to indicate position-and-hold, or push back (prior to taxiing). Difficult for a local controller to know if aircraft was cleared for takeoff or is in position-and-hold.
- A few bugs - leader line management, data block overlap, few personal adjustment.

PEQ Item 20 – In order of preference, what additional features would you desire for the TODDS?

- To be used in conjunction with ASDE-X/STARS all on the same page.
- Heavy in data block.
- Incorporate data with ASDE-X to reduce equipment clutter.
- Ability to program individual "pref sets" that can be loaded in order to customize TODDS display for each controller.
- Vector lines. Hold short for taxiways.
- I cannot think of any that I have not already mentioned.
- None I can think of.

- Maybe inhibit some information, or fix overlap issue to reduce confusion of who's who.
- Need to separate runway bays better. Need to show departure strip highlighted. Need a box to check when aircraft is cleared to land.
- Maybe a flashing tag for ground request.
- The ability to call up what route you issued to the aircraft without canceling and resending the D-Taxi.
- Get the data tags to not cross over each other. Somehow get them to go in order without overlapping.
- Need position-and-hold indicator prior to going orange. Need to know who is moving prior to them moving, so that all personnel in cab know what is going on. TODDS needs mile markers for final. Maybe hold short markings should be in red. Never experienced missed hold due to volume of taxiing traffic.
- Personal adjustments/fonts/sizes/etc.

PEQ Item 21 – Do you have any additional comments regarding the experiment?

- Scenarios are a little too long.
- Good stuff, fun to work, good job by the "pilots." Maybe auto drop when you're finished with the aircraft.
- Great experiment!! Thanks for the opportunity.
- I think this system would be very useful at busy airports.
- Excellent equipment. Sometimes very easy to become distracted from traffic priorities.
- No. The experience was great. Really neat equipment. I would love to have it at my facility instead of strips.
- Great job.
- Great job! Keep it up!
- Would like to try it in IFR conditions.
- Enjoyable experiment. Definitely not for those that are not computer savvy.
- Great job guys!
- Would like to come back if continued study is available. Need more time and less complex operation to handle efficiently. Thanks for the opportunity.
- It has been a very good experience and I've enjoyed it.